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Silvicultural Systems, Cutting Methods, and Cultural Practices for Black Hills Ponderosa Pine

Robert R. Alexander

Abstract

Guidelines are provided to help forest managers and silviculturists develop even- and uneven-aged cutting methods and associated silvicultural practices needed to convert ponderosa pine forests in the Black Hills into managed stands, and maintain them for a variety of resource needs. Guidelines consider stand conditions and insect susceptibility. Cutting practices are designed to maintain water quality, improve wildlife habitat, enhance opportunities for recreation and scenic viewing, and provide wood products.

Cover Photo.—Typical Black Hills ponderosa pine stand.

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INTRODUCTION

Black Hills ponderosa pine (*Pinus ponderosa* var. *scopulorum*) (SAF Type 237) (Barrett et al. 1980) occupies about 1.5 million acres in the Black Hills of South Dakota and Wyoming, and associated Bearlodge Mountains of eastern Wyoming (fig. 1). Scattered smaller aggregations of ponderosa pine stands with similar characteristics occupy about 250,000 acres of butte-top and scarp sites to the north and south of the Black Hills and Bearlodge Mountains in Nebraska, Wyoming, and Montana (Boldt et al. 1983).

These forests form a unique, isolated segment of the interior ponderosa pine type. Ponderosa pine, the principal timber species, usually grows in pure, climax stands (Alexander 1974, Boldt and Van Deusen 1974). The main timber-producing stands are the crystalline core area, characterized by rough to rounded hills and divides generally ranging from 4,300 to 6,000 feet (1,310 to 1,830 m) elevation, and the limestone plateau. In the eastern Black Hills, the limestone plateau forms a narrow ridge that occasionally flattens out to narrow uplands with elevations of 3,600 to 4,400 feet (1,095 to 1,340 m); in the western Black Hills, it forms wide, rather level divides separated by narrow, steep valleys that range in elevation from 4,500 to 7,000 feet (1,370 to 2,135 m) (fig. 2).

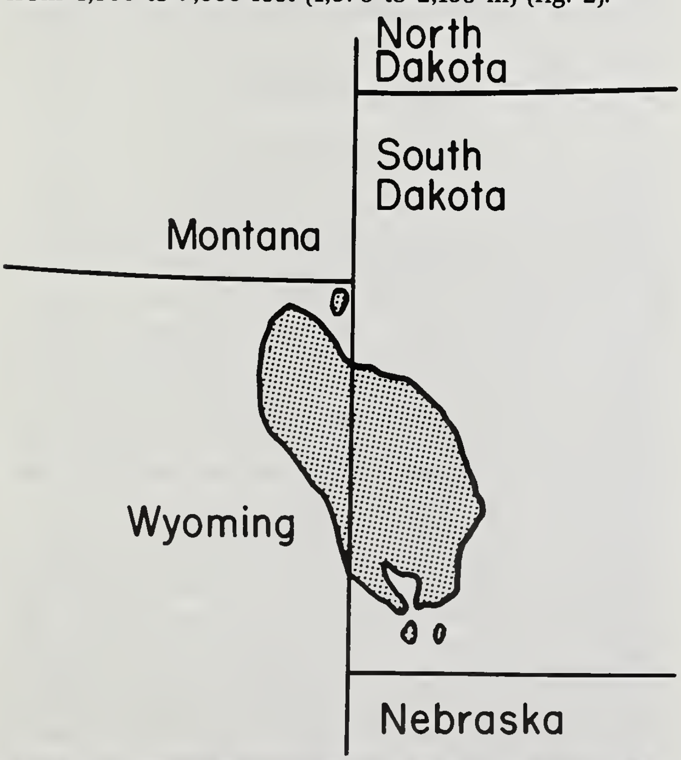

Figure 1.—Occurrence of ponderosa pine in the Black Hills and Bearlodge Mountains (Alexander 1974).

White spruce (*Picea glauca* (Moench) Voss) forms nearly pure, mostly even-aged stands on cool, moist sites where it is considered the climax forest type. Ponderosa pine is seral on these sites. Only about 2% of the commercial forest land currently is dominated by white spruce; but it is gradually replacing seral pine stands on cool, moist sites as a result of fire control, pine-killing insects and diseases, and silvicultural practices. On drier sites, spruce may mix with but eventually is replaced by pine (Boldt et al. 1983). A recently completed study of forest vegetation in the Black Hills and Bearlodge Mountains identified and described 12 forest habitat types. White spruce is the self-reproducing climax tree species on two of these habitat types (*Picea glauca/Vaccinium scoparium* and *P. glauca/Linnaea borealis*).[2]

Stands of quaking aspen (*Populus tremuloides* Michx.) occupy about twice as many acres as white spruce but, for the most part, less permanently. Most aspen stands are seral, replacing pine or spruce only temporarily following disturbance. Stands of bur oak (*Quercus macrocarpa* Michx.) of tree form are confined mostly to low elevation bottoms on the eastern and northern margins of the Black Hills. However, a scrub form of oak also mixes with pine on some upland sites in the northern Black Hills and Bearlodge Mountains. On these sites, if dominant pine cover is lost, because of cutting, fire, or other disturbance, oak brush may occupy the site. Natural replacement of oak by pine is a very slow process; artificial reforestation also is difficult and expensive (Boldt et al. 1983). Aspen has been identified as a climax overstory tree in one habitat type (*Populus tremuloides/Corylus cornuta*), and bur oak in two habitat types (*Quercus macrocarpa-Ostrya virginiana* and *Q. macrocarpa/Symphoricarpos occidentalis*).[2]

Black Hills ponderosa pine forests produce a variety of wood products in large quantities. They also provide forage for livestock and big game; habitats for a variety of wildlife; water for domestic, industrial and agricultural uses; and recreational opportunities for millions of people. Demands on the forest are increasing, and how Black Hills ponderosa pine forests are managed will affect all resources and uses. For example, if timber production is the primary objective, growing stock levels should be high; but forage production and water yields can be increased substantially only at low stocking levels. Carefully planned harvests that maintain low to medium growing stock levels generally are considered appropriate to improve developed recreational opportunities and enhance foreground esthetics. Improvement of middleground and background esthetics generally require open forests, and

[2]*Hoffman, George R., and Robert R. Alexander. Forest vegetation of the Black Hills National Forest of South Dakota and northeastern Wyoming: A habitat type classification. (Manuscript in preparation.)*

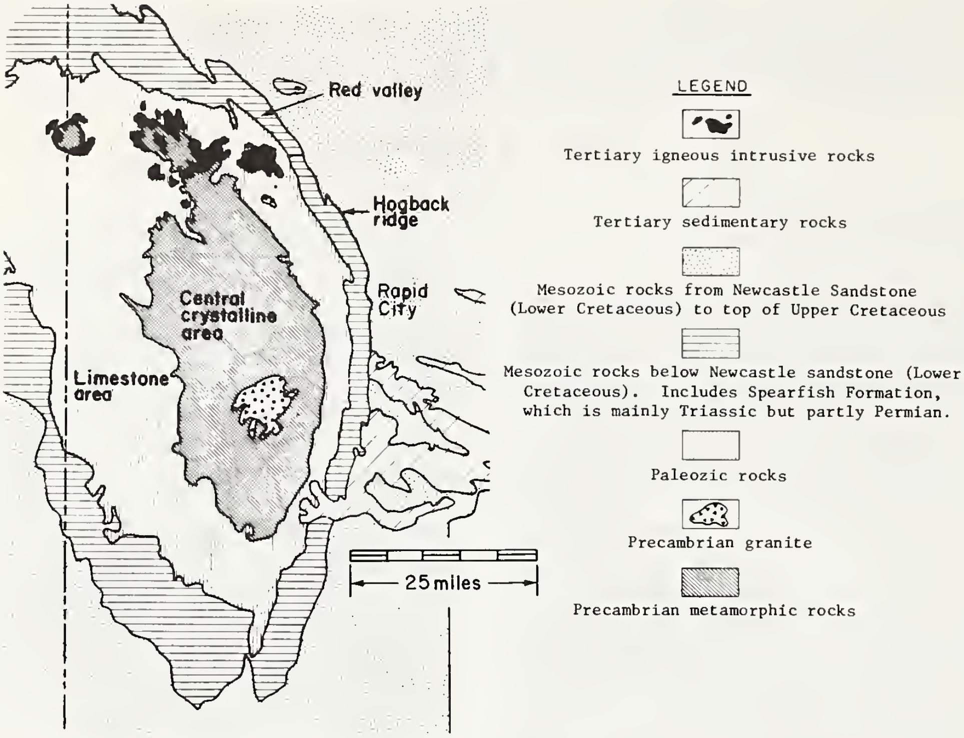

Figure 2.—Generalized geologic map of the Black Hills (Boldt and Van Deusen 1974).

stands with both low and high growing stock levels to provide contrasts. Wildlife habitat requirements vary from uncut, a variety of cutover lands, to open forests.

Although land-use planners and land managers must increasingly direct their efforts toward multiple uses, these practices must be based on sound silvicultural principles of the forest type involved. They must understand the tradeoffs between the timber and other resources, as well as physical, social, and economic considerations. The predominance of ponderosa pine seriously limits the diversity in forest vegetation and complicates management efforts to maintain or increase associated forest types (Boldt et al. 1983).

Black Hills ponderosa pine has been managed longer and more intensively than any other Rocky Mountain timber type. Regeneration silviculture has been learned by experience during a century of harvesting that has included all even- and uneven-aged cutting methods. This has led to the conversion of old-growth stands to well-stocked, managed stands of second-growth, with little or no reduction in productivity. Management of Black Hills ponderosa pine is somewhat simplified, because these forests naturally reproduce readily and prolifically, and are free of dwarf mistletoe (*Arceuthobium* spp.) (Boldt and Van Deusen 1974).

Ponderosa pine is the dominant overstory species on seven habitat types (*Pinus ponderosa/Juniperus communis, P. ponderosa/Arctostaphylos uva-ursi, P. ponderosa/Physocarpus monogynus, P. ponderosa/Carex heliophila, P. ponderosa-Juniperus scopulorum, P. ponderosa/Quercus macrocarpa*, and *P. ponderosa/Symphoricarpos albus*).[2]

NATURAL STANDS

Age-Class Distribution

The age-class distribution of ponderosa pine in the Black Hills is in better balance than for any other area or forest type in the Rocky Mountains. Although there are isolated stands in the Black Hills as old as 200+ years, most of the commercial forest land is occupied by stands in the 50- to 130-year-old age classes, with harvesting concentrated in the 50- to 100-year-old age classes (Green 1978). While 57% of the area is stocked with sawtimber-sized stands, only 9% of these stands are classified as old growth. The remaining sawtimber stands (48%) are young, immature to mature sawtimber.

Twenty-six percent of the commercial forest land is in poletimber stands. The stands originated from either wildfires in the late 1800s or early timber harvesting. They vary in density and vigor, depending upon site and whether or not they have been thinned; but most stands have been thinned at least once. About 15% of the Black Hills ponderosa pine is classified as seedling and sapling stands that originated after cutting or fire. Because Black Hills ponderosa pine regenerates easily after cutting and low intensity fires where a seed source remains,

only about 2% of the ponderosa pine lands are classified as nonstocked. However, not all nonstocked lands can support ponderosa pine forests, or else they can support only open-grown, low density forests (Green 1978).

Reaction to Competition

Black Hills ponderosa pine is rated shade intolerant (Baker 1948). However, it is not as intolerant as common associates, such as quaking aspen, bur oak, and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.). It is much more intolerant than white spruce, however.

Ponderosa pine is a climatic climax over much of the Black Hills; but fire and logging has converted, partially or completely, some climax ponderosa pine stands to other plant communities—usually aspen or bur oak. In the northern Black Hills on cool, moist sites, ponderosa pine is a long-lived seral to white spruce. Moreover, white spruce has the potential to replace ponderosa pine on many more acres than it now dominates.

Stand Conditions

Ponderosa pine forests in the Black Hills grow in a variety of stand conditions that may vary from irregular, open-grown and poorly stocked to even-aged and overstocked. A common stand condition is two-storied. However, such stands do not occupy as much of the commercial ponderosa pine lands in the Black Hills as in the past. This two-storied structure is a transitory stand condition resulting from repeated partial cutting harvests made from the early 1920s through the 1960s. A few two-storied stands resulted from natural mortality in uncut old-growth stands from the combined impacts of bark beetles, lightning, and wind (Boldt and Van Deusen 1974).

A typical two-storied stand is comprised of a light reserve of mature or overmature sawtimber-sized trees scattered irregularly above a well stocked stand of young trees (fig. 3). Sawtimber stocking in the first story of a typical stand usually will be quite variable, both in amount and distribution. On all but the very best sites, the upper limit of overstory stocking probably will be about 70 square feet of basal area. At higher stocking levels, especially if the trees are distributed uniformly, too few seedlings become established to form a manageable second story (Boldt and Van Deusen 1974).

Large variations in stocking also are common in the second story; but overstocking is the normal condition when overstory basal area is 70 square feet per acre or less. Frequently, the development of the second story has been severely retarded by heavy and prolonged competition from within and above. As a result, it is not unusual to find "reproduction" stands as old as 50 to 60 years that have not advanced beyond large seedling or small sapling size. Trees in such stands generally tend to be slender and whippy, with weak, sparse crowns. The largest and most vigorous trees, or groups of trees, usually are those growing on sites that are least influenced by competition from the overstory. Where overstory stocking is light and

Figure 3.—Transitory two-storied ponderosa pine stand in the Black Hills (Alexander 1974).

irregularly distributed, there may be enough of the better developed trees to form a new stand of fair to good quality after the overstory is removed and the understory is precommercially thinned (Boldt and Van Deusen 1974).

Two-storied stands may be pure pine or mixed pine and white spruce. In mixed conifer stands, the first story usually is pine of low to medium density (up to 50 square feet of basal area per acre). The second story is either pure white spruce or a pine-spruce mixture of seedlings, saplings, and small poles, even-aged and well to overstocked. In mixed pine-spruce stands, ponderosa pine usually is a long-lived seral on all but the driest sites.

A little less than one-half of the commercial forest land in the Black Hills is occupied by immature, single-storied ponderosa pine. About 50% of these stands are classified as poletimber. They differ from many even-aged forests, because crown class differentiation tends to be slow and diameter distributions skewed toward the smaller diameter classes. These traits reflect the inherent tolerance of Black Hills ponderosa pine to interstand competition and its tendency to stagnate (Boldt and Van Deusen 1974).

Most of these single-storied stands originated as natural reproduction following heavy harvest cutting, fires, or massive bark beetle epidemics shortly before and after 1900. The remainder has been created by seeding and planting of burns and other deforested sites, and by complete removal of the overstory in two-storied stands.

In stands typically dense at the time of establishment and left to develop naturally, more than 50% of the trees may be expected to remain in diameter classes below the mean stand diameter to biological maturity (fig. 4). Diameters tend to be more normally distributed in stands that have been thinned moderately one or more times (fig. 5).

Single-storied, mature to overmature ponderosa pine stands are represented widely in the Black Hills by many stands that are discrete, but too small in area to warrant separate accounting in inventory. Most of these stands appear to have originated as reproduction following the killing of patches of mature trees in virgin, old-growth

stands by bark beetles, localized wildfires, lightning, and wind. Common examples are isolated small patches of yellowbark poles or small sawtimber scattered through a matrix of more extensive two-storied and immature single-storied stands (fig. 6). Typically, these are crowded groups of old-growth trees, which were bypassed in past harvest cutting for saw logs, because of small stem size or poor quality. Some patches have received light intermediate cuts for posts or poles; many others have received no treatment (Boldt and Van Deusen 1974).

Areas in the Black Hills occupied by multistoried stands have increased in recent years. In many cases, these stands have developed as a result of gradual invasion by pine into upland parks and abandoned fields. In other situations, white spruce has invaded ponderosa pine stands. Typically, the stands are composed of several ages of pine seedlings, saplings, and small poles clustered around scattered parent trees. In later stages of the invasion process, clumps of trees may merge to form more

Figure 4.—Stagnated sapling stand; 60 years old; 5,800 stems per acre; average diameter 2.5 inches b.h. (Boldt and Van Deusen 1974).

Figure 5.—Even-aged immature ponderosa pine stand; 60 years old; thinned in 1934 and again in 1964 (Boldt and Van Deusen 1974).

Figure 6.—A mature 150-year-old single-storied stand left uncut by past harvests (Boldt and Van Deusen 1974).

or less continuous stands of irregular structure. The openings into which the pines are expanding usually support grasses and forbs, with few shrubs or deciduous trees. Most of these stands are developing on an ecotone. They tend to advance and retreat with cyclic changes in the climate and other environmental pressures. However, in the past 80 years, advances have occurred more often than retreats. Prolonged protection from fire evidently has favored invasion by pine in many upland parks, and white spruce on the coolest and wettest sites.

Throughout the Black Hills where heavy cutting of ponderosa pine stands has occurred, a pine-deciduous mixture may exist. Normally, the hardwood component is either aspen or bur oak. Pine usually grows as scattered trees throughout the stand, or may sometimes be found as small pockets of mature trees. Crowns of the scattered pines may be either above or below the relatively low crown canopy of the deciduous species. Because of the seral nature of these mixtures, they range from the early stages of sprouts to full grown oak brush or aspen trees. Fire probably is the most frequent cause, although bark beetles or wind also may be responsible. Occasionally, heavy harvest cutting, which removed most of the pine, provided openings that permitted expansion of aspen or oak by sprouting (Boldt and Van Deusen 1974).

DAMAGING AGENTS

Insects

Bark Beetles

Mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is the only native insect that is capable of devastating Black Hills pine forests. At epidemic levels, this pest has

killed entire stands of pine, greatly influencing the distribution of age classes throughout the area. An extremely serious outbreak occurred between 1895 and 1910, destroying an estimated 1 to 2 billion board feet of timber. More recently, serious buildups of mountain pine beetle has occurred in the 1960s and again in the 1970s in the northern hills. Severe and widespread losses were averted by concentrated efforts of insect control crews. During the increase in insect populations to destructive levels, annual pine mortality may exceed 100,000 trees (Thompson 1975).

Adult beetles attack ponderosa pine in midsummer, usually July 15 to September 1 (Schmid 1972). Beetles carry blue-stain fungi that hastens the death of the tree. They create egg galleries, mate, and deposit eggs in the phloem layer. Larvae then feed on the phloem, and in conjunction with blue-stain fungi, girdle and kill the tree. The first indications of attack are pitch tubes on the trunk where the beetles have entered, and brownish dust in the bark crevices and around the base of the tree (fig. 7). Trees severely attacked in the summer die almost immediately but usually do not begin to fade until the following spring. Needles change from green to yellow-green, sorrel, and finally rust brown before dropping off years later. During outbreaks, mountain pine beetles usually kill trees in groups rather than individual trees scattered throughout the stand. These groups enlarge as subsequent generations of beetles continue the infestation, or new adjacent groups may be attacked. Groups may vary from 2 to 3 to 100 or more trees (McCambridge and Trostle 1972).

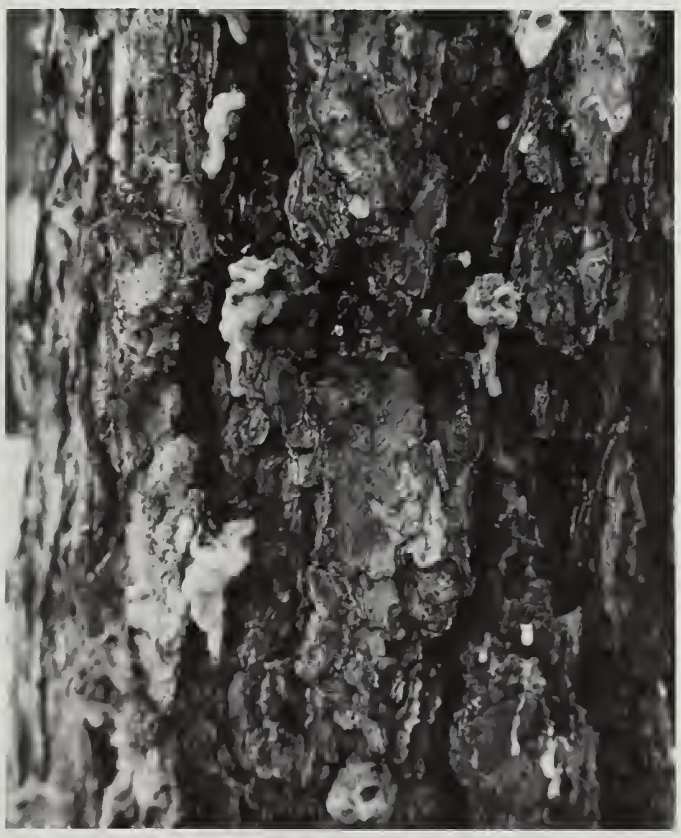

Figure 7.—Pitch tubes on ponderosa pine attacked by mountain pine beetle (Boldt and Van Deusen 1974).

All stands are not equally susceptible to attack. Epidemic outbreaks usually are associated with stands in which average stand diameter is at least 11 inches d.b.h., most of the trees are at least 6 inches in diameter, and stands overcrowded (150 to 260 square feet of basal area per acre) and under stress (Sartwell and Stevens 1975). Infestations usually do not begin in trees smaller than 6 inches d.b.h.; but as groups of trees are killed, smaller trees, intermingled with larger trees, may be attacked and killed. Although natural factors, such as a sudden lowering of fall temperatures or prolonged subzero winter temperatures, nematodes, woodpeckers, and parasites may reduce populations, they cannot be relied upon to control outbreaks (McCambridge and Trostle 1972). Direct control of outbreaks with chemicals is expensive and often only a temporary action until potentially susceptible trees can be cut. High value trees in campgrounds and recreation areas may be protected by preventive sprays. Slash piles covered with clear plastic during warm seasons probably will reach temperatures high enough to afford some control. This treatment is appropriate on small areas, such as around home construction.

The red turpentine beetle (*Dendroctonus valens* LeConte) attacks the base of trees and freshly cut logs and stumps of ponderosa pine (Furniss and Carolin 1977). It is not an aggressive tree killer but frequently weakens trees, making them susceptible to other bark beetles. Populations may increase in areas where logging has occurred for several consecutive years and then may move to adjacent stands. Attacks are characterized by reddish pitch tubes on the lower portion of the stem and heavy frass around the base of the tree. Damage seldom is serious enough to warrant treatment, except in high-value areas. Chemical control is the most effective way to control these beetles.

The pine engraver beetles (*Ips* spp.) also are potentially destructive in sapling and pole stands, although they normally are secondary insects in the Black Hills. Pine engraver populations commonly develop in logging slash, especially if it is shaded or does not dry out quickly. The most effective control is removing or burning large slash and exposing small slash to direct sunlight and wind to dry it rapidly (Sartwell et al. 1971).

Other Insects

Other insect pests generally do not cause widespread losses but can be locally serious. Tip and shoot moth larvae may cause distorted or forked crowns and dead terminal and lateral shoots; sawflies, pine butterflies, and pandora moths can defoliate trees. Control of these insects usually is expensive and difficult.

Diseases

Red Rot

Red rot (*Dichomitus squalens* (Karst.) Reed=*Polyporus anceps* Pk.), which causes a white-pocket rot, is one of

the major causes for loss of sound wood in commercial stands (fig. 8). When losses from red rot are combined with those from the brown cubical rots, the percent of scalable defect rises markedly with increasing tree age (Hinds 1971). Both immature and mature, and vigorous and declining trees are susceptible to infection. Even though virtually no economic losses are sustained by immature trees, red rot should be considered a disease of all age classes, except seedlings and saplings (Andrews 1955, 1971).

Infection becomes established in living trees through the branches. Branches larger than 1.5 inches in basal diameter are 20 times more likely to be avenues through which the infection spreads than are smaller branches. Nearly all the decay develops from airborne spores released by fruiting bodies associated with sap rot of dead material. The sporophores continue to develop annually for about 6 years. The spores lodge in small openings in the bark of dead branches and probably germinate immediately if moisture is favorable. After germination, the fungus develops a pad of mycelium between bark and wood, from which the branch wood itself is infected. The infection then spreads toward the bole through both wood and pith of the branch (Boldt and Van Deusen 1974).

Branches can be attacked by red rot fungus from the time they begin to have deadwood (the whole branch need not be dead) until they have been dead about 20 years, provided they have retained their bark. It is very rare for broken, dead branches to become infected. A tree with large, dead, bark-covered branches is a likely candidate for red rot infection. Because infection occurs through dead branches, the possibility of multiple entrance points throughout the whole tree stem increases with age. Once the rot reaches the heartwood, it may spread up and down the trunk and coalesce with other decay pockets. In older trees, the decay may be one long column, many small columns, or a combination of both. There is a lag, however, between the time red rot reaches the heartwood and the development of scalable defect. Hinds (1971) found age classes older than 100 years to have substantially greater percentage of scalable defect due to red rot than younger age classes.

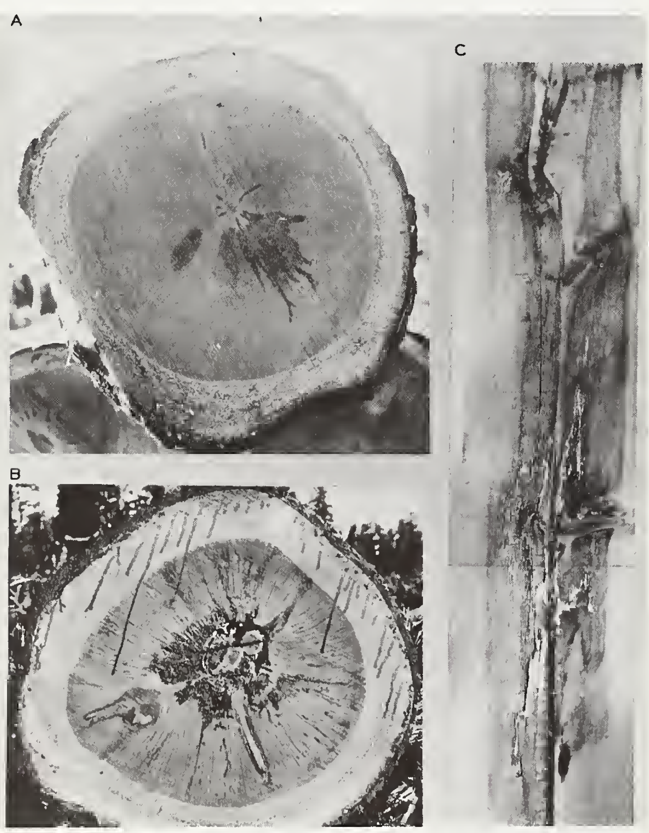

Figure 8.—Red rot in ponderosa pine; (A) incipient decay; (B) advanced decay; (C) advanced decay bordered by incipient decay in heartwood (Boldt and Van Deusen 1974).

Red rot is difficult to detect in living trees, because fruiting bodies rarely develop on them, and then only on dead branches where they merely indicate branch decay. The fungus does not require conspicuous entrance courts, such as wounds, fire scars, or dead tops. No practical method has been found to identify decayed mature and overmature trees and estimate volume losses before cutting (Boldt and Van Deusen 1974).

In immature trees, dead branches generally are reliable indicators of red rot. Undecayed branches resist pressure or break with a crack. Branches in an advanced stage of decay offer little resistance and break as though waterlogged. Suspected branches then must be pruned flush with the trunk to see whether the knots have been penetrated. Heart rot is likely if red rot occurs in the pith. In immature trees, bark-covered branch stubs usually indicate the presence of red rot (Boldt and Van Deusen 1974).

Red rot often can be identified by the characteristic rot pockets that appear in the pitchy base of the branch. Incipient branch decay can be recognized by a continuous white mycelial pad (fig. 9) that binds bark to wood so tightly that pieces of wood stick to the bark when peeled off.

Incidence of red rot infection can be reduced by sound silvicultural practices. Pruning probably is the best cultural treatment in stands where average diameter is small (less than 7 inches d.b.h.). Removing all branches on the butt log in one operation is desirable, although one or more repeat visits may be needed to prune up 17 feet. Pruned branch stubs rarely are the site of red rot infection. The earlier pruning is begun, the more complete will be protection against red rot.

Intermediate cuts to improve volume growth rates also may help reduce the incidence of red rot when infected trees and uninfected trees with many large branches are removed. Stand densities low enough to promote rapid individual tree growth will not necessarily lead to development of large branches (Boldt and Van Deusen 1974).

Western Gall Rust

Western gall rust (*Endrocronarium harknessii* (J. P. Moore) Y. Hiart.) is the second most troublesome disease on Black Hills ponderosa pine, but is a serious problem only in localized areas. Peterson (1959) reported cankers on 7% of the dominant and codominant trees in the Roubaix area. In the Windy Flats area, from one-third

to one-half of the potential crop trees had cankers. Nearly all trees at Windy Flats bore galls (often hundreds per tree) that had killed branches and deformed trees. The rust affects the form, lumber content, and growth rate of pines, and kills individual trees, but does not destroy whole stands (Boldt and Van Deusen 1974).

Gall rust infects pine of all ages. It is most serious in plantations, where it may kill young trees. Most infections occur on twigs of the current season. When the rust invades pine bark, cambial cells of the pine shoot begin to divide rapidly. The result is a woody gall, soft at first, but later as resins and other deposited materials solidify, the gall becomes harder and more decay resistant than normal wood. Galls usually live only a few years, because when they produce fruiting bodies (aecia), they disrupt the host bark and often kill the shoots and stems that bear them.

Cankers are formed on the trunks of trees through infections from branches or wounds (fig. 10) and may cause mortality. However, many trees survive and appear to sustain only slight growth loss. Loss of merchantable length and mechanical weakness are the main disadvantages of cankers.

Elimination of the disease from timber stands is not possible. The aeciospores transmit the disease directly from pine to pine, and windborne spores can be disseminated for hundreds of miles. Thinning of trees containing trunk cankers and pruning lower branches that contain galls minimize the adverse effects of gall rust. However, vigorous trees are more likely to be infected than weak ones, partly because the greater surface area of new shoots on faster growing trees provides greater opportunity for infection (Boldt and Van Deusen 1974). There is considerable evidence of natural resistance to gall rust, however. Some trees in a stand have high levels of infection, whereas adjacent trees have fewer or no galls. This phenotypic expression of resistance should be utilized when marking trees to cut or leave.

Figure 9.—Cross section of dead branch 2 years after infection by red rot; incipient stage in upper half; advanced stage in lower half (Boldt and Van Deusen 1974).


Figure 10.—Gall rust canker on the bole of a Black Hills ponderosa pine.

Dwarf Mistletoe

The Black Hills and Bearlodge Mountains are unique because of the absence of dwarf mistletoe (*Arceuthobium* spp.). Although Black Hills ponderosa pine is susceptible to the disease, the climate will not support the pest. Absence of dwarf mistletoe greatly simplifies the use of cutting methods that depend on natural regeneration.

Other Diseases

Shoestring root rot (*Armillaria* spp.) is common throughout the Black Hills but has caused heavy losses only locally in young plantations, and scattered mortality in sapling and pole-sized trees in thinned stands. Recent research has shown an association of *Armillaria*

with mountain pine beetle infested trees in the northern Black Hills (Lessard et al. 1985). The significance of this relationship to management needs further examination.

Infection by shoestring root rot mainly occurs through mycelial strands or rhizomorphs that grow through the soil. Major symptoms of infection begin with a general decline in vigor or abrupt cessation of growth, followed by yellowing of needles and ultimately death of the tree. Whitish mycelial fans, under the bark near ground line, are characteristic evidence of infection. There are no proven methods of direct control (Boldt and Van Deusen 1974).

Needle cast (*Elytroderma deformans* (Weir) Darker) causes brooming and some defoliation on ponderosa pine in the Black Hills, but is not a serious problem. It is found most often on trees in sheltered situations, such as bottoms or in thickets of reproduction. Lower crowns and interiors of pole-sized and larger trees usually are affected. Trees moderately infected with needle cast have reduced vigor and often are attacked by bark beetles (Childs 1967). Open-growing young trees seldom are injured permanently unless the leader is infected repeatedly. Witches' brooms often develop in crowns of trees after several years of light to moderate infection. These brooms have been the basis for several erroneous reports of dwarf mistletoe in the Black Hills.

Fire

The effect of wildfire on the character of ponderosa pine stands depends upon the age and density of the stand and the intensity of the fire. Low intensity ground fires only kill seedling less than 12 inches tall. Larger seedlings, saplings, and poles may be damaged; but older trees are quite resistant. High intensity crown fires destroy all trees in the burned area. Many large trees have fire scars that reduce the value of the butt log. Concentrations of slash and debris, resulting from logging mature stands, can be lopped and scattered, or piled and burned when conditions permit, to reduce the fire hazard and improve esthetic appearance. Dense young stands should be thinned to reduce the probability of crown fires. Fuel breaks should be placed along heavily traveled roads and around high value sites. Visual appearance of these fuel breaks can be enhanced by clipping the residues.

Controlled or prescribed burning in ponderosa pine forests in the Black Hills offers a management opportunity in mature stands without a manageable stand of advanced reproduction. Low intensity surface fires can be used to prepare seedbeds, reduce competing vegetation, and eliminate fire hazards without damage to the residual stand. In stands where advanced pine regeneration has become established before it is needed or wanted, low intensity ground fires can be used to destroy the unwanted regeneration (Boldt and Van Deusen 1974).

Wind and Snow

Ponderosa pine has a well-developed root system and is one of the more windfirm species in the Rocky Mountains. Although wind is not a primary cause of damage to ponderosa pine in the Black Hills, it can be damaging locally, especially in mature to overmature stands during windstorms accompanied by heavy precipitation. Generally, wind risk is not an important consideration in cutting ponderosa pine. Exceptions are dense stands that have developed over long periods of time and do not have the boles and root systems necessary to withstand wind when opened up with a single heavy cut; those topographic situations of very high wind risk, such as ridgetops, upper windward slopes, and saddles in ridges with shallow soils; stands with many trees with defective boles and root systems; and dense stands growing on sites with a high water table.

Stands that are maintained at reasonable densities from seedling size to end of rotation should be much less susceptible to wind and snow damage. Trees in such stands develop sturdier stems and better anchorage in response to gradual increases in stress, and are able to withstand normal wind and snowloads. Snowbend and breakage occurs more often in sapling and small pole-sized trees. Windthrow is more common in large pole and small sawtimber-sized stands (Boldt and Van Deusen 1974).

Animals

Cattle are responsible for most livestock damage. Trampling as the cows walk along plowed furrows is the most common damage. Cattle rarely graze or browse on seedlings. Sheep may browse the tips of very young seedlings. Occasionally cattle will rub on individual small saplings, scraping off bark, and breaking branches and stems. Fencing out livestock until the trees are small saplings is the most practical protection (Boldt and Van Deusen 1974).

Deer (*Odocoleus* spp.) do not ordinarily browse on pine seedlings to the extent that plantation protection is needed. Trees can recover from random browsing with little loss of growth. Initial successes with chemical repellents indicates that long-term protection to pines may be possible (Dietz and Tigner 1968).

About 15 genera of small mammals that eat pine seed are found in the Black Hills and Bearlodge Mountains; but only two, *Microtus* spp. and *Peromyscus* spp., cause serious seed losses. These mice also can cause nearly complete failures among seedlings in plantations by girdling stems under the snow during winter.

Both cottontail (*Sylvilagus* spp.) and jackrabbits (*Lepus* spp.) are known to girdle seedlings or to clip off leaders and succulent branch tips. Frequently, the portion nipped off is not eaten, but is left on the ground near the original plant.

Of all the rodents, porcupines (*Erethizon dorsatum* Brandt) cause the most damage to trees. The trees are never completely immune to porcupine depredations—seedling to sawtimber sizes may be attacked. The most desirable trees, dominant and codominant crown classes, are the ones most often attacked (Van Deusen and Myers 1962). Where porcupine activity is heavy, many plantation trees, not just an occasional individual, have been deformed or killed.

Poisoning probably is the most effective method for controlling rodent losses in seedlings and plantings. Grain treated with compounds such as zinc phosphide, applied at 1 to 3 pounds per acre, apparently offers satisfactory control. In direct seeding operations, the seeds themselves may be coated with rodenticides (Boldt and Van Deusen 1974).

Damage from porcupines and rabbits can be controlled with strychnine-treated salt blocks, installed in bait boxes scattered throughout plantations or natural stands. Bait boxes must be constructed so that larger animals, such as sheep, calves, or deer, cannot be poisoned accidentally. A few losses of squirrels and other animals that are nondestructive to plantations may be unavoidable.

Birds are not known to cause any serious losses of seeds or seedlings in this area. Of the more than 200 species that have been seen in the Black Hills and Bearlodge Mountains, about 30 are known seedeaters. The seasonal bird populations and number of species that favor pine seeds are both small.

Seeds used in direct seeding operations are coated with aluminum powder to make them less subject to bird losses. Some minor seed losses may occur from birds, such as red crossbills (*Loxia curvirostra* Linnaeus) and black-capped chickadees (*Parus atricapillus* Linnaeus) taking seeds out of tree-borne cones. Natural reproduction normally is too abundant for such seed losses to be important.

Sapsuckers (*Sphyrapicus* spp.) sometimes bore into ponderosa pine stems to expose the tender tissues of the inner bark, an important component of their diet.

CUTTING HISTORY

Ponderosa pine forests in the Black Hills have provided a variety of wood products since they were first cut in the mid–1870s. During the past century, most of the area's unreserved and operable forests have been cut over once, and many acres have received multiple partial cuts. Large tracts that were logged free of regulatory restraints—before establishment of the Forest Reserve in 1897—were commercially clearcut and stripped of all trees large enough to produce a railroad tie or mine timber (Boldt and Van Deusen 1974).

After establishment of the Forest Reserve and imposition of rudimentary harvest controls, a few large sales specified cutting of all timber, alive and dead, larger than a minimum diameter limit. Because this approach led to clearing large areas, most subsequent sales made in the next few years required retention of two or more seed trees per acre on each cutover. This type of timber harvesting persisted through the early 1900s, when a two-cut shelterwood was adopted as standard practice.

Beginning in the mid–1920s, individual-tree selection cutting became standard practice. The main reason for this change was to permit rapid coverage of large acreages of overmature timber urgently in need of silvicultural treatment to reduce risk and anticipated mortality. Use of the selection cutting method continued until the mid–1950s, when even-aged management and shelterwood cutting became the standard harvesting practice. Initially, the revised guides called for gradual removal of mature stands in three light cuts spaced 20 years apart, with retention of a few "insurance" trees above the replacement stand for an additional 20 years. On the ground, this conservative version of the standard shelterwood cutting method was barely distinguishable from the individual-tree selection cutting practice that it replaced. In the 1960s, the two-cut shelterwood again became the standard harvesting practice, with timing of the removal cut contingent on establishment and development of the understory. With this change in practice, timber harvesting experience on the Black Hills National Forest returned to where it started at the turn of the century (Newport 1954).

The long history of cutting, together with losses caused by insects, diseases, winds, and fires, nearly has eliminated the original old-growth sawtimber stands on about one-half of the commercial forest area. Only light stands of scattered, old-growth remnants are left on the remaining acres (Boldt and Van Deusen 1974). Despite all of the harvesting and losses to destructive agents, growing stock has not been depleted. In fact, it actually has increased in some instances. Nearly 5 billion board feet of timber has been harvested from the Black Hills.

REGENERATION SILVICULTURAL SYSTEMS

Harvesting practices in the Black Hills evolved largely as a trial-and-error process. However, only in rare instances have past timber harvesting operations been silviculturally damaging. Most cutting has been reasonably successful, as evidenced by the scarcity of poorly or nonstocked acres and the absence of any pronounced reduction in growth or allowable cut during the liquidation of old-growth (Boldt and Van Deusen 1974).

Important lessons learned from these diverse harvesting experiences include: (1) even-aged silvicultural systems are best suited to Black Hills ponderosa pine; (2) within the even-aged system, any of the standard regeneration cutting methods may be a valid option under appropriate circumstances; (3) the shelterwood cutting method offers more advantages and entails fewer disadvantages than either the seed-tree cutting or clearcut methods; and (4) uneven-aged silvicultural systems are not a desirable option for timber production in Black Hills ponderosa pine because of silvical characteristics and stand conditions; but selection cutting methods are valid options in special situations (Boldt et al. 1983).

The objective of each regeneration system is to harvest the timber stand and obtain adequate reproduction. The choice of cutting method in ponderosa pine stands depends upon management goals; but stand conditions, diseases and insect susceptibility, and the risk of potential fire damage that vary from place to place on any area limit the options available for handling individual stands.

EVEN-AGED CUTTING METHODS—MATURE STANDS

This section is limited to mature single- and two-storied pure ponderosa pine or pine-white spruce mixtures.

Multistoried ponderosa pine stands are not considered, because these stands generally have developed as a result of gradual invasion by pine into parks and abandoned fields. If conversion to managed pine is desired, it would require harvesting isolated seed parent trees, site preparation, and planting. Deciduous pine mixtures also are excluded, because in these stands, aspen or bur oak is the dominant stand component. Conversion to pine is difficult and expensive, because it usually is a scattered component. Moreover, the wildlife habitat and scenic beauty values of the hardwood component normally are more valuable than if the stands were converted to ponderosa pine. Management should be directed at maintaining the pine component while increasing the value of the hardwood component.

Management with Advanced Reproduction

Simulated Shelterwood Cutting

This cutting method, generally applicable to transitory, two-storied stands, removes the overstory from a manageable stand of advanced reproduction. It simulates the final harvest of a standard shelterwood.(fig. 11).

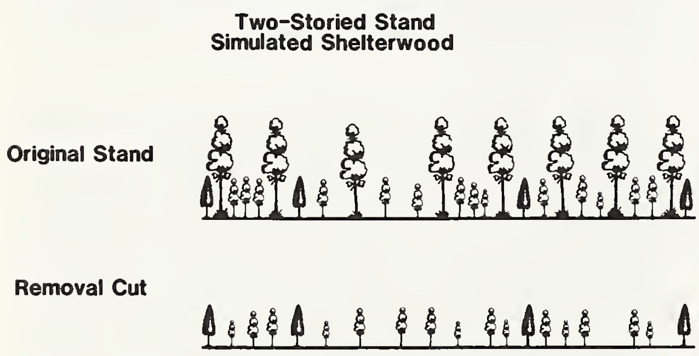

Figure 11.—Sequence of entries with a simulated shelterwood in a transitory two-storied ponderosa pine stand.

Stands may be pure ponderosa or mixed conifer, with a ponderosa pine overstory and either a pine-white spruce or white spruce understory. Understory trees respond to release after cutting; but wide variations in age, composition, quality, and quantity of advanced reproduction require careful evaluation of the potential for future management. One approach is followed if the advanced reproduction is to be managed, another if a manageable stand is not present, cannot be saved, or the manager chooses to destroy it and start over.

Prelogging evaluation.—The initial examination must answer the following questions. (1) How much of the area is stocked with acceptable seedlings and saplings, and will that stocking insure a satisfactory replacement stand? (2) Can it be logged economically by methods that will save advanced reproduction? (3) Is the timber volume too heavy to save advanced reproduction if it is removed in one cut? (4) How much of the area will require subsequent natural or artificial regeneration, either because advanced reproduction is not present or will be damaged or destroyed in logging?

Because any kind of cutting is likely to destroy a portion of the advanced growth (often as much as 50%), a manageable stand of advanced reproduction before cutting should contain at least 600 acceptable seedlings and saplings per acre. Stands or portions of stands not meeting these criteria have to be restocked with subsequent natural or artificial regeneration.

Cutting and slash disposal treatment.—Mature and overmature trees should be cut to release advanced reproduction and harvest merchantable volume. Seed sources need not be reserved from cutting unless required for fill-in stocking. The size, shape, and arrangement of units cut is not critical for regeneration; but to be compatible with major key uses, they should be irregular in shape, with the long axis parallel to the contour to better blend into the landscape.

Protection of advanced reproduction begins with a well-designed logging plan. Logging equipment and activity must be rigidly controlled to minimize damage to advanced reproduction and disturbance to soil. The least damage occurs when skidroads are located at least 200 feet apart and marked on the ground before cutting. Skidding equipment should be moved only on skidroads. Where possible, trees should be felled into openings at a herringbone angle to the skidroad to reduce disturbance when logs are moved onto the skidroad. It may be necessary to deviate from a herringbone felling angle in order to drop the trees into openings. In this case, the logs should be bucked into short lengths to reduce skidding damage. Furthermore, the felling and skidding operations must be closely coordinated, because it may be necessary to fell and skid one tree before another is felled. Dead sound material and snags that are felled should be skidded out of the area to minimize the amount of slash and unmerchantable material left in the woods for subsequent disposal. In stands with heavy volumes per acre, it may be necessary to remove the overstory in more than one cut.

Slash treatment then should be confined to areas of heavy concentrations, as required for protection from fire and insects or preservation of esthetic values. Slash also must be treated carefully to avoid damage to advanced reproduction. If trees are felled into openings as much as possible, a minimum of turning and travel with brush dozers will be needed to concentrate the slash for burning. Slash piles should be large enough to confine burning to the smallest total area possible.

Postlogging reevaluation.—Even with careful logging and slash treatment, some advanced reproduction will be damaged or destroyed. The area must be surveyed to: (1) Determine the extent of damage to the reproduction. At least 300 acceptable seedlings and saplings per acre must have survived to consider the area adequately stocked. Areas that do not meet these standards need fill-in or supplemental stocking. (2) Plan stand improvement—cleaning, weeding, and thinning—to release crop trees. Cutover areas should not be considered in an adequate growing condition until the crop trees are free to grow and the necessary fill-in planting or natural regeneration is complete.

Management for Regeneration After Cutting

Clearcutting

This method harvests the timber crop in one step to establish a new stand. Although clearcutting is an acceptable silvicultural option for mature single-storied and two-storied pure pine and mixed pine-white spruce stands without a manageable stand of advanced reproduction, it has not been widely used in the Black Hills. However, management objectives, such as increasing water yields, creating wildlife openings, and controlling mountain pine beetle, may make the use of clearcuts optimum in some situations in the Black Hills.

If stands are to be clearcut and regenerated naturally, the cut should be made either during or immediately after a good seed crop or the size of the cleared area should be small enough to be within the effective seeding distance of trees around the perimeter of the opening. In the Black Hills, seed dispersal from standing ponderosa pines is limited to about 130 feet. Therefore, openings should be about 260 feet in width where seed producing stands surround the opening, and 150 feet if seeding will be from one side only. Clearcut openings can be in the form of blocks or strips; but to improve the visual appearance, openings with irregular boundaries are preferred with the long axis of the opening laid out along the contour.

Clearcutting has the advantages of allowing the replacement stand to develop free of overstory competition, and there is no risk of loss of an on-site seed source. However, it produces more logging residue than shelterwood cutting and provides little control over competing ground cover. Moreover, the probability of natural regeneration establishment is reduced if success depends upon seedfall from trees harvested on the area, especially if large openings are cut.

Shelterwood Cutting

This method harvests a timber stand in a series of cuts. It is applicable to single-storied ponderosa pine or two-storied pine or mixed conifer stands without a manageable stand of advanced reproduction. In a standard shelterwood, the new stand regenerates under the shade of a partial overstory canopy. The final harvest removes the shelterwood and permits a new stand to develop. Group shelterwood (a modification of the shelterwood method) is applicable in stands composed of irregular mosaics of small even-aged groups or patches of trees. The new stand regenerates in small openings that leaves trees standing around the margins as a seed source. Openings are too small (2 acres or less) to be classified as a clearcut (USDA Forest Service 1983). This kind of cutting has been incorrectly called a modified group selection, but differs from a selection cut in the way the growing stock is regulated.

Standard shelterwood is the preferred even-aged option for ponderosa pine in the Black Hills. Shelterwood cutting requires careful marking of individual trees or groups of trees to be retained and close supervision of logging. The following recommendations for shelterwood cutting practices are keyed to broad stand descriptions based largely on experience and insect problems (Boldt and Van Deusen 1974, Boldt et al. 1983). Stands are pure pine unless otherwise indicated.

Mature single-storied stands.—These stands may appear to be even-aged but often contain more than one age class (fig. 12). Codominants form the general level of the canopy; but the difference in height between dominants, codominants, and intermediates is not great. Stocking varies from uniform to irregular.

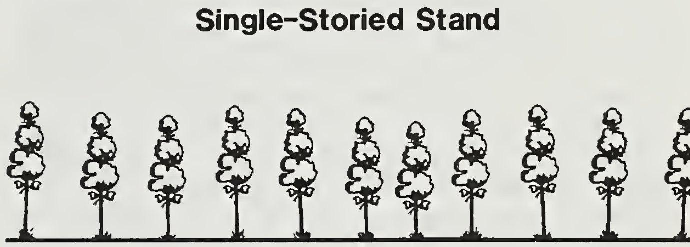

Figure 12.—Single-storied stand—not a common occurrence in Black Hills ponderosa pine.

Because mature single-storied ponderosa pine stands in the Black Hills only occupy small areas in any locality, they should be handled according to the treatment prescribed for a transitory two-storied stand without a manageable understory of advanced reproduction. However, when trees in these inclusions are considerably larger than trees in the matrix stand, it is desirable to limit harvesting in the single-storied stand to a sanitation salvage until trees in the surrounding stand reach about the same size as trees in the inclusion. After stand sizes have equalized, the included stand should be opened gradually to match the stocking of the matrix stand, and then may be treated similarly to the end of the rotation.

If the inclusion is small (2 acres or less) and occurs in a two-storied stand with a manageable stand of seedlings or small saplings in the second story, it normally would be given a removal cut 10 to 20 years before the final harvest that removes the overstory in the matrix stand. If the inclusion is larger than 3 acres, it should be given a shelterwood seed cut. The overwood should be removed at the same time as the final harvest in the two-storied matrix stand. If the inclusion is 3 acres or less, another regeneration option is a clearcut, with seeding from the side by overstory trees in the matrix stand.

Mature two-storied stands.—These stands appear to be two-aged but may contain more than two age classes (fig. 13). The top story resembles a single-storied stand. The second story is composed of younger trees of smaller size. If the stand is more than two-aged, either or both the top story and second story may contain more than one age class.

In mixed conifer two-storied stands, the overstory usually is pure pine. The second story is seedling- and/or sapling-size pine and white spruce or white spruce only. Stocking in both pure and mixed stands varies from uniform to irregular. However, stocking in the second story is not sufficient to provide a replacement stand when the overstory is removed. The manager has the op-

tion of either saving as much of the advanced growth as possible and supplementing it with subsequent regeneration or destroying the advanced growth and starting over. In most situations, the first option has been chosen.

A two-cut shelterwood usually is appropriate in stands that have been entered previously. A three-cut shelterwood often is more desirable in stands not entered previously or only lightly entered, especially in stands with a large white spruce component, because spruce is susceptible to windthrow.

Using a two-cut shelterwood, the first cut normally will remove between 50% to 60% or more of the basal area (fig. 13). This is the seed cut. Trees retained should be in vigor classes A and B insofar as possible, but selected dominants and codominants can be left if needed to maintain the residual BA, even when they are in vigor classes C and D, if they do not have dead or dying tops. Good crowns and evidence of past cone production are characteristics of good seed trees. Avoid cutting holes in the canopy by distributing the cut over the entire area. In mixed conifer stands, if the top story is pure pine, handle as a pure stand. If the top story is of mixed conifer composition, a choice must be made as to which species is to be favored in the regeneration. To favor white spruce, lighter cuts (40% to 50% of the BA) that remove as much of the pine as possible are recommended. To favor ponderosa pine, heavier cuts (60% to 70% of the BA) that retain as much of the pine as possible are recommended.

The second entry should be the final harvest to remove the remaining original stand and release the reproduction. It cannot be made until the new stand of reproduction is established. Normally, this will be between 5 and 20 years after the seed cut.

The manager has other options, including cutting less than the recommended basal area, making more entries, and spreading the cut over a longer time by delaying the final harvest until the new stand is tall enough to create the appearance of a high forest. This is not recommended where mountain pine beetles limit how stands can be managed. Moreover, delaying the final harvest is not likely to be cost effective.

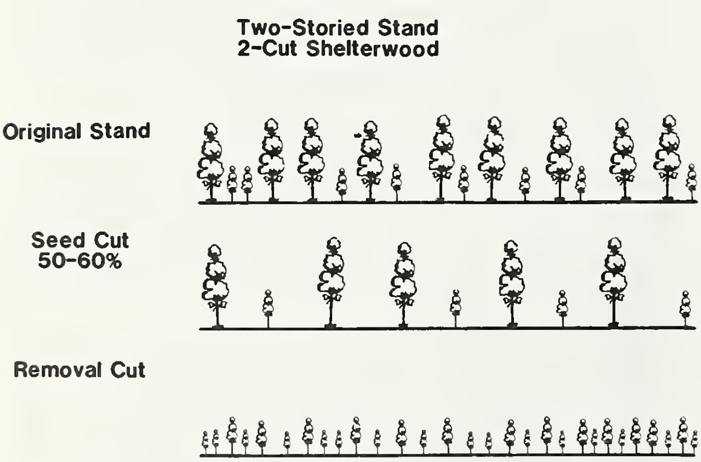

Figure 13.—Sequence of entries with a two-cut standard shelterwood in a two-storied ponderosa pine stand.

Using a three-cut shelterwood, the first entry should remove 30% to 40% of the basal area on an individual-tree basis (fig. 14). This initial entry is a preparatory cut, because it probably does not open up the stand enough for a significant amount of pine reproduction to become established. The general level of the canopy should be maintained by removing some trees in each overstory crown class. The cut should come from the poorest vigor class trees; but openings larger than one tree height in diameter should be avoided by distributing the cut over the entire area. In mixed conifer stands, a three-cut shelterwood will tend to favor white spruce, because it will begin to regenerate under the preparatory cut.

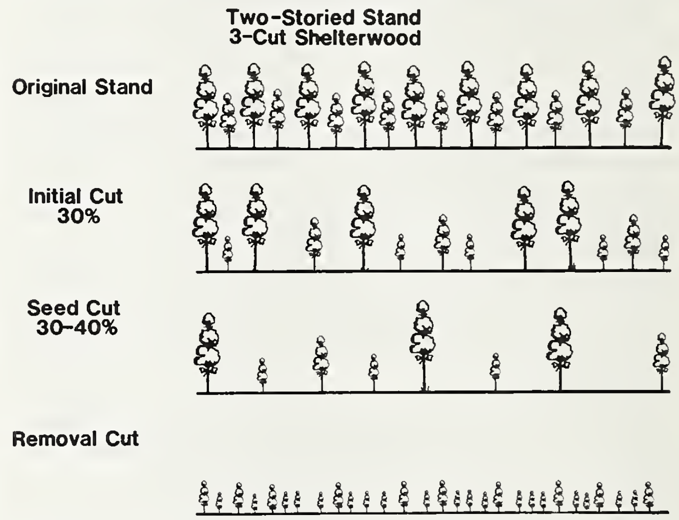

Figure 14.—Sequence of entries with a three-cut standard shelterwood in a two-storied ponderosa pine stand.

The second entry into the stand can be made 5 to 10 years after the first cut. This is the seed cut and should retain 30 to 50 square feet of basal area or remove 30% to 40% of the original basal area. This cut opens up the stand so that pine regeneration can become established. The largest and most vigorous dominants and codominants should be reserved as a seed source; but avoid cutting openings in the canopy larger than one tree height in diameter by distributing the cut over the entire area, even if it means leaving trees in the C and D vigor classes with poor seed production potential. In mixed conifer stands, heavier cuts that retain as much of the pine as possible will favor pine in the replacement stand, whereas lighter cuts that retain more white spruce will favor spruce in the replacement stand.

The last entry into these stands is the final harvest that should remove all of the remaining original overstory. It should not be made until a manageable stand of reproduction has become established; but the cut should not be delayed beyond this point, because the overwood hampers the later growth of the seedlings, and saplings tend to be more easily damaged by the removal.

The manager also has the option of removing less than 30% of the basal area at any entry and making more entries; but they should not be made at more frequent intervals. The cut will be spread out, and continuous high

forest cover will be maintained for a longer time. This option is not recommended where either mountain pine beetles or economics limit how stands can be handled.

Openings may occur naturally in regenerated two-storied stands. In other clumpy or irregularly-spaced stands, openings may have resulted from the break-up of stands associated with beetle attacks, fires, or logging. For stands where managers wish to retain clumpy or irregular spacing, either a two- or three-cut group shelterwood is an option.

With a two-cut alternative, the first cut can remove between 40% to 50% or more of the basal area in a group shelterwood (fig. 15). The group openings can be two or three times tree height; but the area cut over should not exceed about one-half of the total. Openings should be irregular in shape to simulate natural openings. One additional entry can be made in the stand to remove the remaining original basal area in group openings up to two to three times tree height.

With a three-cut alternative, the first entry should remove about 30% of the basal area using a group shelterwood (fig. 16). Openings should be kept small and conform to the natural arrangement of the stands, with not more than one-third of the area cut over at any one time. The second entry into the stand should not be made until the first openings have been regenerated. This cut removes about 30% to 40% of the original basal area without cutting over more than an additional one-third of the area. The final entry should remove the remaining groups of merchantable trees.

With both alternatives, the timing of the final entry depends on how the manager decides to regenerate the openings. Using natural regeneration, the final harvest either (1) must be delayed until the trees in the original openings are large enough to provide a seed source, (2) harvesting follows a good seed year on site, (3) these openings are planted, or (4) a standard shelterwood is applied to the last groups. In the last case, it will require at least one additional entry to remove the overstory after reproduction has established.

With either alternative, the manager may choose to remove less than the recommended basal area and cut over less than the recommended basal area at any time.

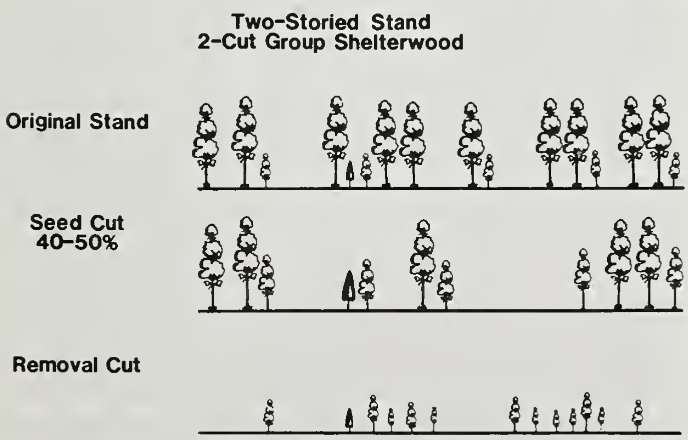

Figure 15.—Sequence of entries with a two-cut group shelterwood in a two-storied ponderosa pine stand.

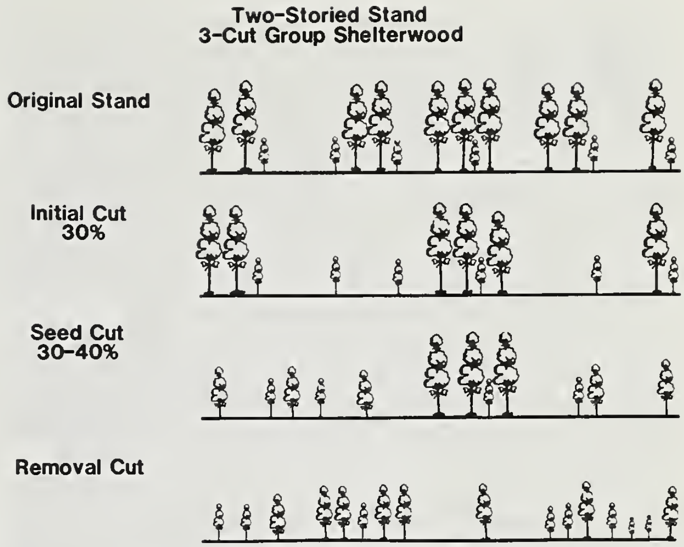

Figure 16.—Sequence of entries with a three-cut group shelterwood in a two-storied ponderosa pine stand.

This will require more entries and spread the cut over a longer time, but each new cut should not be made until the openings cut the previous entry have regenerated. Furthermore, the last groups cannot be cut until either there is sufficient seed on site from the trees harvested, an outside seed source, the openings are planted, or a standard shelterwood is applied to the last groups.

Group shelterwood cutting is not applicable in pure pine stands where mountain pine beetles impose limitations, because the interval between initial cutting and final harvest is likely to be too long to prevent serious loss of beetle-susceptible trees.

Modifications for insect problems.—Mountain pine beetles have killed extensive amounts of unmanaged ponderosa pine, particularly in dense, single-storied second-growth stands in the northern Black Hills. Extensive tree-killing has been associated with stand densities ranging from 150 to 260 square feet basal area per acre and mean tree diameters of about 11 inches d.b.h. and larger (Sartwell and Stevens 1975).

If mountain pine beetle is present in the stand at an endemic level or in adjacent stands at epidemic levels and less than the recommended basal area to be removed in the first cut is in susceptible trees, any attacked trees and all of the most susceptible trees should be removed in the first cut. This will include most of the larger diameter trees in mature single- and two-storied stands. Dense stands of understory trees and young and immature groups and patches should be thinned. In immature single-storied stands, most of the trees will be in the susceptible category. Although generally the larger the diameter the greater the susceptibility, current knowledge does not permit differentiation of tree susceptibility when diameters are all about the same. In this case, leave trees should be dominants of good vigor with potential for seed production. Provision should be made to salvage attacked trees. Moreover, the second cut should be made within 5 to 10 years after the initial cut.

If more than the recommended basal area to be removed in the first cut is in susceptible or attacked trees,

the manager has three options: (1) remove all the trees in single- and two-storied stands, followed by thinning in dense young stands, patches, or groups; (2) remove the recommended basal area in attacked and susceptible trees, thin the dense stands, patches, and groups of young immature trees, and accept the risk of future losses; or (3) leave the stand uncut. However, the benefits of thinning are not likely to be realized if the thinned area is small and surrounded by unthinned stands sustaining an attack. If the stand is partially cut or left uncut, some trees in the smaller diameter classes will survive.

If a single- or two-storied stand is sustaining an increasing or epidemic infestation and the manager chooses to either partially cut or leave the stand uncut, there is a risk of an outbreak that could destroy most of the infested merchantable stand and spread to adjacent stands.

Time of cutting is important in reducing attacks by *Ips* and turpentine beetles. While it is unlikely that sawlog cutting operations can be shut down during attack periods, thinning operations can be scheduled for times of minimum activity, preferably after September 1.

Cutting to save the residual stand.—In shelterwood cutting, protection of the residual stand from logging damage is a primary concern. The residual stand includes merchantable trees left after standard shelterwood, reproduction established after the seed cut in standard shelterwood, and reproduction established after each cut in group shelterwood. Before the final harvest is made with standard shelterwood and before each entry with group shelterwood, the manager must determine if there is an acceptable stand of reproduction. Furthermore, the stand must be reevaluated after final harvest in standard shelterwood and after each entry with group shelterwood to determine the need for supplemental stocking. The same criteria used to evaluate advanced reproduction with a simulated shelterwood applies here.

Protection begins with a well-designed logging plan at the same time of the first cut. To minimize damage, the same protection measures for management with advanced reproduction apply here.

Slash disposal and seedbed preparation.—Some treatment of logging slash and unmerchantable material may be needed after each cut, especially if *Ips* populations are observed. Treatment should be confined to concentrations and that needed to reduce visual and insect impacts. Piling and burning slash may cause damage to the residual stand and is expensive and time consuming. Spot burning usually is more effective if stands are open and slash accumulations are kept away from residual trees. Treatment in stands often can be limited to lopping and scattering, chipping along the roadway, and hand piling and burning to minimize damage, especially where utilization of small material for small posts and firewood removes much of the slash (fig. 17). In group shelterwood cutting, if there is not a manageable stand of advanced reproduction, dozers equipped with brush blades can be used to concentrate slash for burning in the openings. Piles should be kept small to reduce the amount of heat generated.

On areas to be regenerated by new reproduction, a partial overstory canopy or trees standing around the margins of small openings provide two of the basic elements necessary for regeneration success—a seed source within effective seeding distance and an environment compatible with germination, initial survival, and seedling establishment. The manager must make sure that the third element—a suitable seedbed—is provided after the regeneration cut where standard shelterwood cutting is used, and after each cut where group shelterwood or cuttings to convert irregular stand structures to managed stands is used.[3] In the Black Hills and Bearlodge Mountains, logging disturbance usually is adequate for site preparation. In stands with heavy fuel loading, prescribed burning is a successful site preparation method.

Figure 17.—Sequence of entries with a seed-tree cutting in a two-storied ponderosa pine stand.

Seed-Tree Cutting

This method harvests nearly all of the trees on an area in one cut. A few of the better trees are left well distributed over the area to reseed naturally. Seed trees may or may not be harvested after regeneration is established.

Seed-tree cutting is an acceptable silvicultural option in mature single-storied and two-storied pure pine and mixed conifer stands without a manageable stand of advanced reproduction. Many acres of Black Hills forests have been harvested and successfully regenerated by this method (Boldt and Van Deusen 1974). In both single-storied and two-storied stands, the first cut should be heavy, removing about 90% or more of the residual volume. The light reserve stand normally will contain five to ten trees per acre to reseed the area (fig. 18). The residual stand then is cut after the area is regenerated.

Seed-tree cutting has advantages over shelterwood cutting. The seed trees offer less overstory competition to the development of the replacement stand; removal of seed trees is likely to result in less damage to the replace-

[3]*Discussion of the silvical requirements and cultural practices necessary for successful ponderosa pine regeneration in the Black Hills is beyond the scope of this paper. For this information, see Boldt and Van Deusen (1974).*

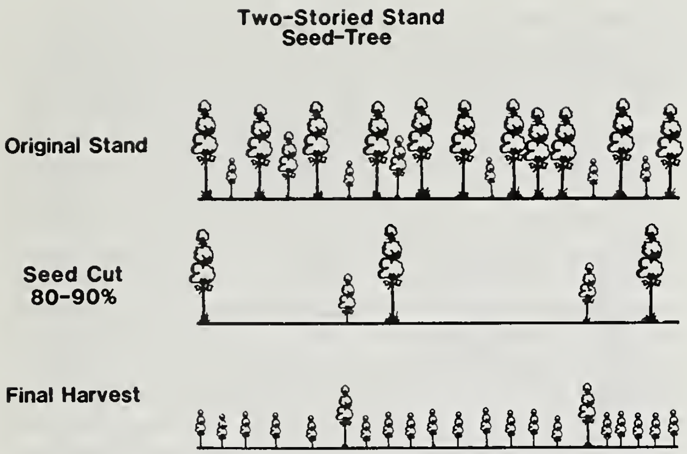

Figure 18.—Utilization of all usable material, including firewood, can minimize the need for slash disposal.

ment; and because there are fewer seed trees, there is less likelihood of an overly dense replacement stand. However, the heavy first entry usually leaves a large amount of logging residue that is both unsightly and a fire hazard. Moreover, leaving only a few seed trees risks the loss of seed source, especially in densely grown stands. Trees that have developed together over long periods of time mutually support each other and are vulnerable to windthrow and windbreak when suddenly fully exposed to the wind. The limited overstory competition that is favorable to the development of tree seedlings also favors the development of undergrowth. Consequently, the site may become occupied by shrubs, graminoids, and forbs at the expense of seedlings.

Procedures outlined for cutting to save the residual stand, slash disposal, and seedbed preparation for shelterwood cutting methods should be followed here.

UNEVEN-AGED CUTTING METHODS—MATURE STANDS

Single- and two-storied ponderosa pine stands are best maintained under even-aged cutting methods, preferably some form of shelterwood. However, these stands may occur as uneven- to broad-aged by even-aged groups and patches. Moreover, uneven-aged management may be more compatible or desirable for some management objectives or resource needs. For example, the impact on the forest should be as light as possible in areas of steep topography and erosive soils or where management goals include maintenance of continuous forest canopy, vertical diversity, etc. Uneven-aged management may be more appropriate for these conditions and goals.

Uneven-aged management includes cultural treatments, thinnings, and harvesting necessary to maintain continuous high forest cover, provide for regeneration of desirable species, either continuously or at each harvest, and provide for controlled growth and development of trees through the range of size classes needed for sustained yield of forest products. Managed uneven-aged stands are characterized by trees of many sizes intermingled singly or in groups. Cutting methods do not produce stands of the same age that are large enough to be recognized as a stand. Forests are subdivided into recognizable units that can be located on the ground on the basis of timber type, site, logging requirements, etc., rather than acreage in stand-age classes. Growing stock is regulated by setting (1) a residual stocking goal, in terms of basal area or volume, that must be maintained to provide adequate growth and yield; (2) a diameter distribution goal that will provide for regeneration, growth, and development of replacement trees; and (3) a maximum tree size goal. In addition, a decision must be made on how to handle small trees. Both individual-tree selection and group selection cutting methods can be considered in stands with irregular to all-aged structure (Alexander 1986; Alexander and Edminster 1977a, 1977b).

Individual-Tree Selection Cutting

This regeneration cutting method harvests trees in several or all diameter classes on an individual basis. Stands regenerate continuously. The objective is to provide a stand with trees of different sizes and age classes intermingled on the same site (USDA Forest Service 1983). Choice of trees to be cut depends on their characteristics and relationship to stand structure goals set up to regulate the cut. This cutting method provides maximum flexibility in choosing trees to cut or leave, and is appropriate only in uniformly spaced stands with irregular to all-aged structure. However, because of ponderosa pine's silvical characteristics, individual-tree selection cutting is difficult to implement and maintain in pure stands. In mixed pine-white spruce stands, it is a better option; but few pines are likely to establish after the initial cutting.

Group Selection Cutting

This regeneration cutting method harvests trees in groups ranging from a fraction of an acre up to about 2 acres (USDA Forest Service 1983). It is similar to a group shelterwood, except in the way the growing stock is regulated. The area cut is smaller than the minimum feasible for a single stand under even-aged management. Trees are marked on an individual-tree basis; but emphasis is on group characteristics, which means trees with high potential for future growth are removed along with trees with low growth potential. Loss in flexibility is offset partly by the opportunity to uniformly release established regeneration and reduce future logging damage. When groups are composed of only a few trees, the method can be used together with individual-tree selection cutting in mixed stands. This cutting method is most appropriate in irregular to broad-aged mixed or pure multistoried ponderosa pine stands that are clumpy, groupy, or patchy. However, it can be used in uniformly spaced stands with the size, shape, and arrangement of openings based on factors other than the natural stand conditions (Alexander 1986; Alexander and Edminster 1977a, 1977b).

Stand Structure Goals

Control of Stocking

The first step in applying a selection cut to a ponderosa pine stand is to determine the residual stocking level to be retained. Because total stand growth for many species under uneven-aged management does not differ greatly over the range of stocking levels likely to be management goals, stocking levels set near the lower limit, where no growth is lost, concentrate increment on fewest stems. This reduces time required to grow individual trees to a specific size and requires a minimum investment in growing stock (Alexander and Edminster 1977b).

The residual stocking level with the best growth potential and most desirable appearance in pure or mixed ponderosa pine stands varies with species composition, management objectives, productivity, diameter distribution, etc. In old-growth ponderosa pine stands, stocking usually varies from 60 to 180 square feet of basal area per acre in trees in the 4-inch and larger diameter classes. Basal areas above 150 square feet per acre probably represent overstocking. While no guidelines are available for uneven-aged stands, residual stocking levels of GSL 60 to 160 are suggested for managed even-aged stands, with the site quality normally associated with ponderosa pine in the Black Hills (Alexander and Edminster 1981). These levels should be useful in estimating initial residual stocking goals, in terms of square feet of basal area per acre, for that part of the stand that eventually will be regulated under uneven-aged management (Alexander 1986, Alexander and Edminster 1977b).

While these general recommendations probably are adequate to start with, use of yield tables for even-aged stands in setting stocking goals for uneven-aged stands assumes there is little difference between the growing stock of the two other than a redistribution of age classes over a smaller area (Bond 1952). This may be true when stands without a manageable understory of advanced growth are harvested by a group selection method. The result is likely to be a series of small even-aged groups represented in the same proportion as a series of age classes in even-aged management. If advanced growth of smaller trees has become established under a canopy of larger trees, however, a different structure may be developed with either individual-tree or group selection methods. Growth space occupied by each age or size class is being shared (Reynolds 1954). Assuming that damage to understory trees resulting from removal of part of the overstory trees can be minimized, advanced growth will successfully establish a series of age classes on some areas. In this situation, more trees of a larger size can be grown per acre than with a balanced even-aged growing stock (Bourne 1951, Meyer et al. 1961). Nevertheless, without better information, the residual stocking goals set for even-aged management are the best criteria available.

Maximum Tree Size

The second item of information needed is the maximum diameter of trees to be left after cutting. In old-growth ponderosa pine stands in the Black Hills, maximum diameter usually varies from 16 to 26 inches d.b.h., depending on stand density, site quality, species composition, etc. Examination of plot inventory information from unmanaged stands with irregular stand structure suggests that a diameter of 16 to 18 inches can be attained within the time period generally considered reasonable under the narrow range of site quality found in the Black Hills and stocking levels likely to be management goals (GSL 60 to 120). Without information on growth rates in uneven-aged stands or rates of return for specific diameter stocking classes, a 16-inch maximum diameter seems a reasonable first approximation to set for timber production on lands of average site quality. Trees of larger diameter with a lower rate of return on investment may be appropriate for multiple-use purposes (Alexander 1986, Alexander and Edminster 1977b).

Control of Diameter Distribution

Control over distribution of tree diameters also is necessary to regulate yields under uneven-aged management. This most important step is accomplished by establishing the desired number of trees or basal area for each diameter class.

When used with flexibility, the quotient q between number of trees in successive diameter classes is a widely accepted means of calculating diameter distributions in uneven-aged stands (Meyer 1952). Values of q ranging between 1.3 and 2.0 (for 2-inch diameter classes) have been recommended for various situations. The lower the q, the smaller is the difference in number of trees between diameter classes. Stands maintained at a small q have a higher proportion of available growing stock in larger trees, for any residual stocking level, but may require periodic removal of the largest number of small trees in the diameter class when unregulated growing stock crosses the threshold into the proportion of the stand to be regulated (Alexander 1986, Alexander and Edminster 1977b).

Consider, for example, differences in the number of small and large trees maintained at a q level of 1.1, 1.3, and 1.5 in stands with the same residual basal area (80 square feet) (table 1). At all stocking levels considered appropriate for future management goals, many small trees would have to be cut under lower q levels at the threshold diameter class (in this example, the 4-inch class). Fewer larger trees would be retained under higher q levels.

Without experience, data, or good growth and yield information, the best estimate of numbers of trees to leave by diameter classes is to use the lowest q value that is reasonable, in terms of existing and future markets, stand conditions, and funds available for cultural work. Examination of plot data from a wide range of irregularly stocked old-growth ponderosa pine stands indicates that pretreatment distributions are likely to range between 1.2 and 1.5 for 2-inch classes. As a general recommendation, q levels between 1.2 and 1.4 appear to be reasonable initial goals for the first entry into unmanaged stands. For the more shade tolerant white spruce, q levels of 1.4 to 1.6 appear to be reasonable initial entry goals.

Table 1.—Residual stand structure for 80 square feet of basal area (BA) and maximum tree diameter of 16 inches d.b.h. for various q values.

Diameter class	q = 1.1		q = 1.3		q = 1.5	
	No. trees	BA (ft^2)	No. trees	BA (ft^2)	No. trees	BA (ft^2)
4	26.92	2.35	51.73	4.52	83.94	7.33
6	24.49	4.81	39.73	7.80	55.94	10.98
8	22.21	7.75	30.63	10.69	37.29	13.02
10	20.23	11.03	23.56	12.85	24.91	13.58
12	18.40	14.45	18.10	14.22	16.58	13.02
14	16.73	17.88	13.92	14.88	11.06	11.82
16	15.21	21.24	10.71	14.95	7.37	10.29
Total	144.19	79.51	188.38	79.91	237.09	80.10

How to Determine Residual Stand Structure

Once goals for residual stocking, maximum tree diameter, and q levels have been selected, the specific structure for a stand can be calculated, provided that data are available to develop a stand table (Alexander and Edminster 1977b).

An existing old-growth ponderosa pine stand was selected to illustrate the procedure. The actual inventory data for the stand is shown in columns 1, 2, and 3 of table 2. A residual basal area of 80 square feet per acre in trees 4 inches d.b.h. and larger has been chosen. A maximum tree diameter of 16 inches d.b.h. was chosen, because it also appears to be a realistic goal to be attained in a reasonable period of time. Finally, a q of 1.3 was chosen, because it approximates the q in the natural stand and does not require removal of many small trees. A lower q may be feasible; but it would require heavy cutting in lower diameter classes.

To determine the residual stand goal, the value of the residual density parameter k corresponding to a basal area of 80 square feet must be calculated. Values needed for this computation with a q of 1.3 are given in column 4 of table 3. The value of k is computed as

$$k = \frac{80.0}{0.62428 - 0.01678} = 131.6872$$

where 80.0 is the desired basal area per acre, 0.62428 is the table value for the desired maximum tree diameter class of 16 inches, and 0.01678 is the table value for the 2-inch class. Note that the value for the 2-inch class is subtracted from the 16-inch class value, because trees smaller than the 4-inch class are not considered in the management guidelines. Desired residual number of trees in each diameter class (column 4 of table 2) can be directly calculated by multiplying the proper diameter class values given in column 4 of table 4 by the value of k. The desired residual basal area in each diameter class (column 5 of table 2) can be calculated by multiplying the residual number of trees in each diameter class by the tree basal area.

Comparing actual and desired diameter distributions shows where deficits and surpluses occur (fig. 19). To bring this stand under management, the number of trees should be allowed to increase in the diameter classes that are below the idealized stocking curve, with cutting limited to those diameter classes with surplus trees. As a guide, enough trees should be left above the curve in surplus diameter classes to balance the deficit in trees in diameter classes below the curve. However, in this example that was not done, because a deficit occurred only in the 10-inch d.b.h. class. Cutting to the recommended residual stand in the 8-inch d.b.h. class will provide enough trees to meet the stocking goals in the 10-inch d.b.h. class at the time of the next entry. All surplus trees were cut in the other diameter classes. The final stand structure is shown in fig. 20 and columns 6 and 7 of table 2. Columns 8 and 9 show the trees and basal area removed. Note that the ultimate goal of 80 square feet of residual basal area was not attained in the first entry, because no surplus trees were left in the 8-inch d.b.h. class to make up for the deficit in the 10-inch d.b.h. class.

How to Handle Small Trees

The threshold diameter class also must be determined. Calculations often are made down to the 4-inch diameter class by 2-inch classes, because there are often small trees below minimum merchantable diameter, especially in mixed stands. They compete with larger stems for growing space. More important, these trees provide ingrowth into merchantable size classes needed to practice selection silviculture.

Although small trees should not be ignored in inventory and record keeping, it may be neither desirable nor possible to regulate their numbers. In ponderosa pine forests in the Black Hills, minimum merchantable diameter usually varies from 5 to 8 inches. Regulation of the number of trees below this size requires an investment in silvicultural work that may not be recaptured under prevailing market conditions. However, if trees below minimum merchantable size are left unregulated, cutting always must be heavy in the threshold diameter class to bring ingrowth trees down to the desired number. It also means that more growing space is required for

Table 2.—Actual stand conditions and management goals for ponderosa pine stands. All data are on a per acre basis—stand goals q = 1.3, residual basal area 80 square feet, maximum tree diameter 16 inches d.b.h.

Diameter class (1)	Actual stand		Residual stand		Final stand		Cut	
	Trees (2)	BA (3)	Trees (4)	BA (5)	Trees (6)	BA (7)	Trees (8)	BA (9)
4	58	5.06	51.73	4.52	52	4.54	6	0.52
6	41	8.05	39.73	7.80	40	7.85	1	0.20
8	42	14.66	30.63	10.69	31	10.82	11	3.84
10	19	10.36	23.56	12.85	19	10.36	0	0
12	18	14.13	18.10	14.22	18	14.11	0	0
14	19	20.31	13.92	14.88	14	14.79	5	5.43
16	14	19.55	10.71	14.95	11	15.34	3	4.21
18	1	1.77					1	1.77
20	1	2.18					1	2.18
22	2	5.28					2	5.28
Total	215	101.35	188.38	79.91	185	78.02	30	23.43

Table 3.—Values needed to compute k for different q ratios and diameter ranges using basal area as the density measure (Alexander and Edminster 1977b).

2-inch diameter classes (1)	q ratio				
	1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)
2	0.01983	0.01818	0.01678	0.01558	0.01454
4	.09196	.07878	.06842	.06011	.05333
6	.23948	.19241	.15779	.13166	.11151
8	.47790	.36075	.28001	.22253	.18046
10	.81656	.57994	.42691	.32394	.25228
12	1.25990	.84297	.58963	.42825	.32124
14	1.80848	1.14132	.75999	.52966	.38380
16	2.45985	1.46605	.93116	.62428	.43828
18	3.20930	1.80854	1.09780	.70981	.48425
20	4.05043	2.16089	1.25606	.78523	.52209
22	4.97568	2.51618	1.40336	.85042	.55251
24	5.97669	2.86853	1.53820	.90583	.57682

Table 4.—Values needed to compute desired number of residual trees for different q ratios (Alexander and Edminster 1977b).

2-inch diameter classes D_1 (1)	q ratio				
	1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)
2	0.909091	0.833333	0.769231	0.714286	0.666667
4	.826446	.694444	.591716	.510204	.444444
6	.751315	.578704	.455166	.364431	.296296
8	.683013	.482253	.350128	.260308	.197531
10	.620921	.401878	.269329	.185934	.131687
12	.564474	.334898	.207176	.132810	.087791
14	.513158	.279082	.159366	.094865	.058528
16	.466507	.232568	.122589	.067760	.039018
18	.424098	.193807	.094300	.048400	.026012
20	.385543	.161506	.072538	.034572	.017342
22	.350494	.134588	.055799	.024694	.011561
24	.318631	.112157	.042922	.017639	.007707

small trees than called for by the idealized stand structure. Moreover, the higher the threshold diameter class, the greater is the proportion of the stand that is unregulated. More growing space is occupied by trees of low value that will be cut as soon as they cross the threshold diameter (Alexander 1986, Alexander and Edminster 1977b).

Marking Trees

After residual stocking goals have been calculated and a decision has been made on how to handle small trees, the stand must be marked. Marking is difficult, because the marker must designate cut or leave trees, usually with one pass through the stand, based on limited inventory data. At the same time, the marker must apply good silviculture and be aware of economic limitations. As a general rule, good silvicultural prescriptions are more important than strict adherence to structural goals, especially in unregulated stands being cut for the first time. However, marking without a structural goal—or prescribing structural goals that cannot be attained or applied—defeats the objective of regulation.

Because marking for individual-tree selection cutting is more complex than for other systems, some formal control procedure is necessary. Often only an estimate of the initial desired residual diameter distribution is needed. With these estimates, basal areas and number of trees to be removed per acre by diameter classes can be determined. Control is maintained by a process of successive checks of residual versus the goal. For example, the markers systematically should make prism estimates of the residual stand after marking, recording trees by 2- or 4-inch classes on a standard cumulative tally sheet. Periodically, they should convert the prism tally to trees per acre and compare their average prism estimate to the structural goal. Markers then must adjust to any serious deviation from the structural goal, such as too heavy marking in some diameter classes and too light in others. Their next check will determine if progress is being made or if further changes are needed. By this process, the average residual stand should come fairly close to the structural goal (Alexander and Edminster 1977b).

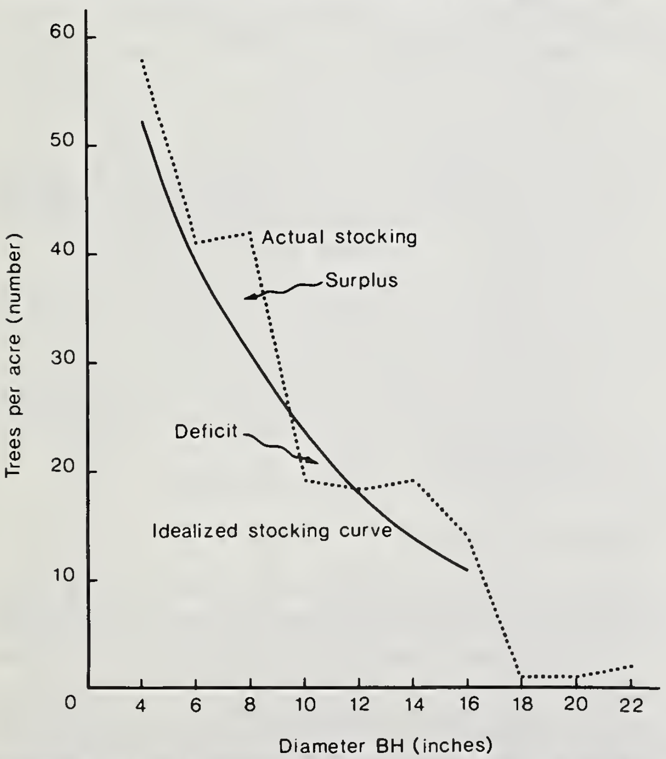

Figure 19.—Actual stocking curve from Black Hills data and the idealized stocking curve based on stand structure goals.

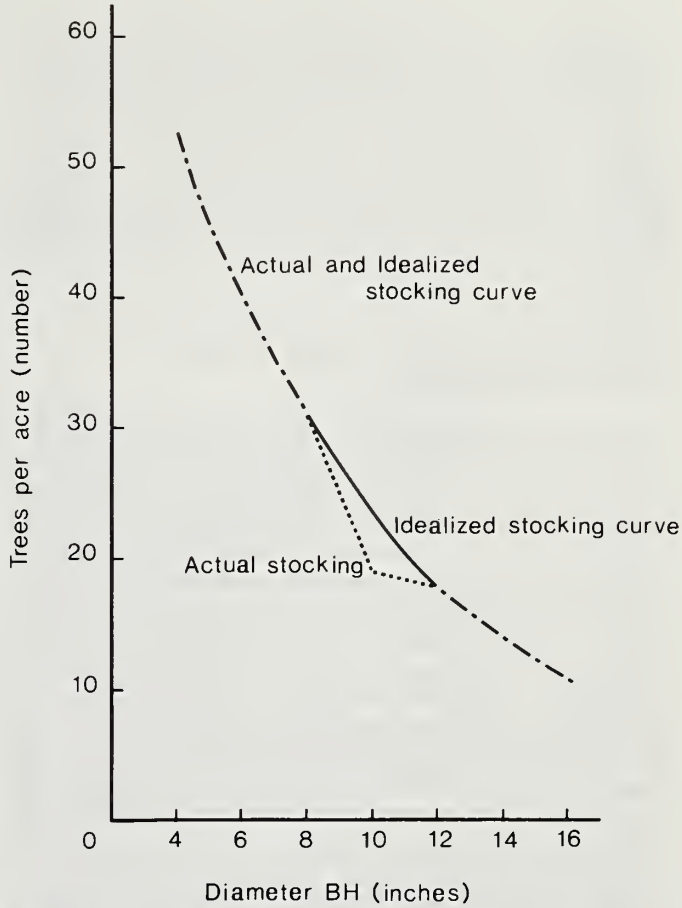

Figure 20.—Actual and recommended stocking curves based on stand structure goals and actual stand structure.

Marking under group selection cutting is less complex than under individual-tree selection, but control over the diameter distribution also is necessary. The objective is to create a series of openings over time and space with each opening containing a given diameter class.

It is not likely that unregulated stands will be brought under management with one entry or even a series of entries. It is more likely that limitations imposed by economics, stand conditions, and mountain pine beetle susceptibility will result in either over- or undercutting, at least in the first entry.

Recommendations for Selection Cutting

These are based on experience and mountain pine beetle susceptibility. Selection cutting methods are ap-

propriate for multistoried pure or mixed conifer stands with irregular or uneven-aged stand structure. Individual-tree selection should be confined to mixed conifer stands with uniform spacing. Group selection can be used in stands with either clumpy, groupy, or patchy spacing, or uniform spacing. Selection cutting methods are not appropriate in stands sustaining a mountain pine beetle attack or in stands where enough beetles are present within the stand or adjacent stands to make successful attacks.

Stand Structure Goals, Cutting Treatments, and Reentry Schedules

While it is desirable to reach the residual stocking goal at the time of the first entry, not more than 50% to 60% of the stand basal area should be removed with individual-tree selection, and the cut should be distributed over the entire area. With group selection, the objective is to create groups of trees distributed over the area, with approximately the same number of groups in each 2- or 4-inch diameter class. Therefore, the amount of area cut at each entry should be proportional to the number of diameter classes. If the stand is groupy, clumpy, or patchy, the size of opening with group selection should be determined by the size of the group, clump, or patch. If the stand is uniformly spaced, the size of the opening should not exceed two to three times tree height. Keep the openings small.

Maximum tree diameter should not exceed that attained in the unmanaged stand. The diameter distribution should be set at a "q" value that most closely approximates the natural "q" value of the stand. However, remember that low q values require cutting more trees at the threshold diameter class, and high q values retain few larger trees. The threshold value should be set at the smallest diameter class practical. All trees below the threshold diameter class are unregulated. Some diameter classes will have a surplus of trees, and some will have a deficit. Surpluses and deficits must be balanced to attain the residual basal area. Subsequent entries should be made at 10- to 30-year intervals. While it would be desirable to enter the stand at 10-year intervals, it is not likely that growth rates initially will permit such frequent entries. The required number of trees in some diameter classes will not be available; therefore, volumes available for cutting may not warrant a 10-year reentry until a controlled diameter distribution is attained.

Protecting the Residual Stand

Protection of the residual stand is critical with individual-tree selection cutting because of frequent entries into the stand once a controlled diameter distribution is attained. Damage can result from felling, skidding, and slash disposal.

Felling damage can be reduced by using group selection and dropping trees in the openings or marking a small clump of trees where felling one large tree will damage several adjacent trees. Procedures outlined for protecting the residual and disposing of slash for shelterwood cutting should be followed here.

MANAGED STANDS— IMMATURE SINGLE-STORIED PONDEROSA PINE

Estimates of Growth Under Intensive Management

About one-half of the commercial ponderosa pine forest land in the Black Hills are occupied by single-storied, second-growth sapling, poletimber and immature sawlog stands. Extremely high densities are common in these naturally regenerated stands. Thinning is needed to reduce stand density early in the life of the stand. Intensive management of these forests provides many opportunities for increasing usable wood production; but estimates of future stand development under various thinning regimes are needed.

Information available on the growth of ponderosa pine from sapling stage to final harvest, under even-aged management, with a shelterwood cutting alternative, is provided by field and computer simulation procedures developed by Myers (1971) and refined by Edminster (1978). The procedures were developed from field data on past growth related to stand density, age, and site quality. Data were obtained from a large number of both permanent and temporary plots established in thinned and natural stands throughout the Black Hills.

Yield simulations discussed in the following paragraphs were made to the same hypothetical initial stand conditions for all growth parameters.

1. Average age at first GSL thinning is 30 years.
2. Average stand diameter is 4.5 inches d.b.h.[4]
3. Stand density is 1,000 tree per acre.
4. Site index is 50-, 60-, 70-, and 80-foot classes, at base age 100 years (Meyer 1961).
5. Projections were made for 50 years (stand age 80 years) and 90 years (stand age 120 years).
6. Thinnings from below were made every 20 and 30 years to growing stock levels (GSL) of 40, 60, 80, 100, 120, 140, and 160, with initial and subsequent entries made to the same growing stock level.
7. A two-cut shelterwood option was used. The seed cut was made 20 years before the final cut and retained 50% of the subsequent GSL.
8. Minimum size for inclusion in board-foot volume determination was 10 inches d.b.h. to an 8-inch top. Volumes were determined from tables prepared by Myers (1964).[5]
9. All entries were made as scheduled.

Diameter Growth

Periodic mean annual diameter growth of Black Hills ponderosa pine is related to stand density and site quality

[4]Average diameter is the diameter of the tree of average basal area; it is not the average of all the tree diameters.

[5]Utilization standards in the Black Hills for board-foot volume determination are changing to 8 inches d.b.h. to a 6-inch top d.i.b. Estimates of board-foot volume growth and production in this paper may be slightly lower than actual board-foot volumes because of the change in utilization standards.

but is affected little by the cutting cycles tested. Cutting cycles do influence average stand diameter, however, because thinning from below increases average diameter at each entry. Actual basal area in a stand with an average diameter of less than 10 inches d.b.h. continues to increase, because periodic thinning does not reduce basal area to a fixed (GSL) amount until an average stand diameter of 10 inches d.b.h. is reached. Consequently, the rate of diameter growth for a given GSL is not constant over time and essentially is a negative exponential function of basal area per acre in the program. In contrast, periodic diameter growth is a linear function of site index, so that differences in diameter growth resulting from site quality are constant throughout the range of GSLs and rotations examined.

Growth rates and changes in diameter resulting from thinning frequency were examined to determine average size of trees relative to rotation age. With a 20-year cutting cycle, for example, trees reach average stand diameters of 10.2 to 18.3 inches d.b.h. after 80 years, and 12.6 to 26.9 inches d.b.h. after 120 years for the range of GSLs and site indexes tested (table 5). On an average site (index 70), with a 20-year cutting cycle, mean stand diameters reached 10 inches d.b.h. at about 50 to 90 years of age for the range of GSLs 40 to 160 (fig. 21) (Alexander and Edminster 1981).

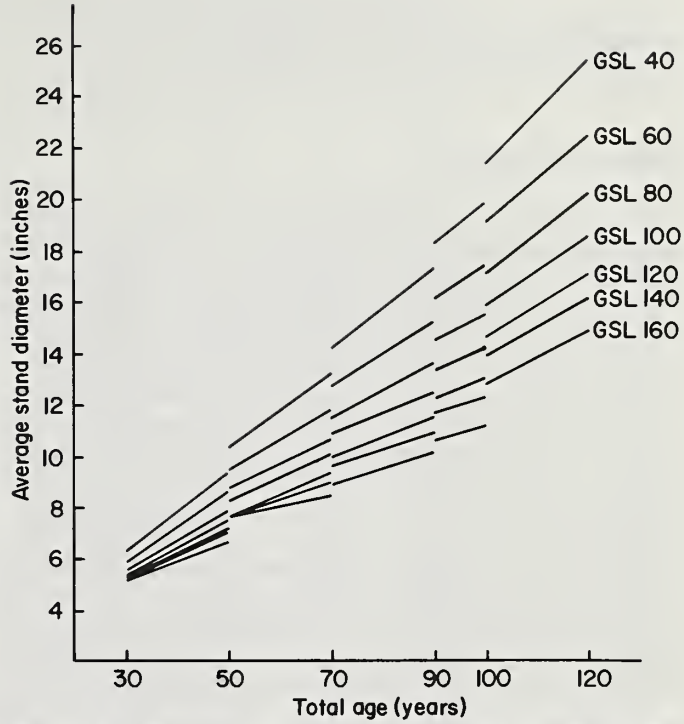

Figure 21.—Estimated average stand diameter of Black Hills ponderosa pine in relation to age and GSL on site index 70 lands, with a 20-year thinning interval.

Height Growth

Periodic mean annual height growth of ponderosa pine increases with site index and decreases with age, but is unaffected by GSLs, cutting methods, or the cutting cycles examined. However, because fewer and, therefore, taller trees are left after each thinning from below, the mean height of the dominant and codominant trees is increased

Table 5.—Estimated average diameter (inches) and number of trees per acre of Black Hills ponderosa pine at final harvest in relation to growing stock level, rotation age, cutting cycle, and site index.

		Growing stock level													
		40		60		80		100		120		140		160	
Rotation age	Cutting cycle	No. of trees	Dia.	No. of trees	Dia.	No. of trees	Dia.	No. of trees	Dia.	No. of trees	Dia.	No. of trees	Dia.	No. of trees	Dia.
Site index 50															
80	20	22	16.5	39	14.8	64	13.3	92	12.3	119	11.5	153	10.8	189	10.2
120		9	23.7	18	20.6	29	18.5	46	16.4	63	15.3	89	13.9	123	12.6
80	30	24	15.9	45	14.1	72	12.7	101	11.7	131	11.0	165	10.4	202	9.8
120		10	22.9	20	19.6	33	17.6	50	15.9	67	14.9	94	13.6	128	12.4
Site index 60															
80	20	21	17.0	38	15.3	60	13.9	83	13.0	111	12.1	145	11.3	180	10.7
120		9	24.4	17	21.5	27	19.4	40	17.6	56	16.3	77	15.0	105	13.7
80	30	23	16.4	42	14.6	67	13.2	92	12.4	124	11.5	155	10.9	192	10.3
120		10	23.5	18	20.7	30	18.5	45	16.7	62	15.6	82	14.6	109	13.5
Site index 70															
80	20	20	17.5	36	15.8	55	14.5	80	13.3	106	12.6	132	12.0	168	11.2
120		8	25.4	15	22.5	25	20.2	37	18.5	52	17.1	66	16.2	90	14.9
80	30	21	17.1	39	15.2	63	13.8	90	12.7	120	11.9	147	11.4	183	10.9
120		9	24.8	17	21.7	28	19.2	41	17.6	56	16.5	74	15.5	99	14.3
Site index 80															
80	20	18	18.3	34	16.4	53	15.0	77	13.7	100	13.1	130	12.3	154	11.9
120		7	26.9	14	23.5	22	21.4	34	19.4	46	18.2	62	16.9	79	15.9
80	30	20	17.7	37	15.8	61	14.1	85	13.2	110	12.6	142	11.8	174	11.2
120		8	25.8	15	22.7	25	20.4	38	18.5	50	17.5	68	16.2	87	15.3

slightly at each entry. The increase is positively correlated with thinning frequency and negatively correlated with GSL (Alexander and Edminster 1981).

Basal Area Growth

Periodic mean annual basal area increment is related to growing stock level, site quality, frequency of thinning, and rotation age. Because actual basal area continues to increase in a stand until average stand diameter reaches 10 inches d.b.h. and thinning reduces basal area to a fixed amount (GSL), the rate of basal area growth for a given GSL is not constant over time. Periodic basal area increment increases as growing stock level increases from 40 to 140, but the rate of increase diminishes as stand density increases. At GSLs above 140, basal area increment declines on all sites. Periodic mean basal area growth also increases as site index increases. Moreover, the differences in basal area growth between site classes become progressively greater as GSL increases. Periodic mean basal area increment is greater with a 30-year cutting cycle than with a 20-year entry at all rotations examined for GSLs 40 to 140 (Alexander and Edminster 1981).

Total Cubic-Foot Volume Increment

Cubic-foot volume production is related to stand density, site quality, rotation age, and frequency of thinning (table 6). Although mean annual cubic volume increment increases as growing stock level and site index increases, the rate of increase diminishes as GSL increases, while the differences in growth between site classes become greater (fig. 22) (table 7). Cubic volume increment for both rotations examined apparently will continue to increase at GSLs above 160 on site index 70 and 80 lands, but level off or decline on site index 50 and 60 lands at GSLs greater than 160. Mean annual cubic volume increment generally is greater with a 120-year rotation and a 30-year cutting cycle for all GSLs and site indexes examined (Alexander and Edminster 1981).

Board-Foot Volume Increment

Board-foot volume production is related to all stand parameters evaluated (table 8). Mean annual sawtimber volume growth increases on site index 70 and 80 lands as stand density increases from GSL 40 to 140. Above GSL 140, growth begins to level off. On site index 50 and 60 lands, growth generally levels off or declines at GSLs above 120 (fig. 23) (table 9).

Board-foot volume growth increases with site quality, and the differences in growth between site classes become greater as GSL increases. Throughout the range of GSLs tested, average annual board-foot increment per acre always is greater for all site classes on a 120-year rotation (fig. 24). There are no practical differences in board-foot volume growth between 20- and 30-year cutting cycles for the range of site indexes and GSLs tested (fig. 25) (table 9) (Alexander and Edminster 1981).

Table 6.—Estimated total cubic-foot volume production per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle (in years), and site index.

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
------ years ------		------------------ *thousand cubic feet* ------------------						
					Site index 50			
80	20	1.91	2.24	2.55	2.80	2.96	3.04	3.12
120		2.95	3.67	4.20	4.56	4.82	4.94	5.04
80	30	2.04	2.37	2.63	2.80	2.96	3.10	3.19
120		3.10	3.80	4.33	4.66	4.91	5.02	5.10
					Site index 60			
80	20	2.39	2.90	3.32	3.61	3.83	3.97	4.06
120		3.71	4.62	5.30	5.88	6.24	6.48	6.67
80	30	2.56	3.02	3.38	3.66	3.90	4.12	4.20
120		3.90	4.81	5.56	6.12	6.50	6.82	6.98
					Site index 70			
80	20	2.94	3.50	4.02	4.44	4.78	5.01	5.13
120		4.48	5.62	6.48	7.19	7.75	8.22	8.46
80	30	3.12	3.72	4.19	4.55	4.81	5.06	5.20
120		4.73	5.90	6.84	7.56	8.16	8.53	8.84
					Site index 80			
80	20	3.50	4.29	4.88	5.32	5.68	5.96	6.16
120		5.26	6.70	7.85	8.78	9.54	9.97	10.26
80	30	3.76	4.42	5.01	5.49	5.82	6.03	6.20
120		5.63	7.04	8.18	9.12	9.86	10.43	10.70

Table 7.—Estimated mean annual total cubic-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index.

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
------ years ------		------ cubic feet ------						
					Site index 50			
80	20	23.9	28.0	31.9	35.0	37.0	38.0	39.0
120		24.6	30.6	35.0	38.0	40.2	41.2	42.0
80	30	25.5	29.6	32.9	35.0	37.0	38.8	39.9
120		25.8	31.7	36.1	38.8	40.9	41.8	42.5
					Site index 60			
80	20	29.9	36.2	41.5	45.1	47.9	49.6	50.9
120		30.9	38.5	44.2	49.0	52.0	54.0	55.6
80	30	32.0	37.8	42.2	45.8	48.8	51.3	52.5
120		32.5	40.1	46.3	51.0	54.2	56.8	58.2
					Site index 70			
80	20	36.8	43.8	50.2	55.5	59.8	62.6	64.1
120		37.3	46.8	54.0	59.9	64.6	68.5	70.5
80	30	39.0	46.5	52.4	56.9	60.1	63.2	65.0
120		39.4	49.2	57.0	63.0	68.0	71.1	73.7
					Site index 80			
80	20	43.8	53.6	61.0	66.5	71.0	74.5	77.0
120		43.8	55.8	65.4	73.2	79.5	83.1	85.5
80	30	47.0	55.3	62.6	68.6	72.8	75.4	77.5
120		46.9	58.7	68.2	76.0	82.2	86.9	89.2

Table 8.—Estimated total board-foot volume production per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index (trees 10 inches d.b.h. and larger to an 8-inch top).

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
------ years ------		------ thousand board feet ------						
					Site index 50			
80	20	4.40	4.88	5.28	5.52	5.60	5.36	4.96
120		11.04	12.96	14.28	15.12	15.36	14.88	13.80
80	30	4.32	4.88	5.04	5.20	5.04	4.72	4.16
120		11.04	13.20	14.28	14.88	15.00	14.04	12.60
					Site index 60			
80	20	5.68	6.40	7.12	7.68	7.84	7.84	7.52
120		13.92	16.80	18.84	20.16	21.24	21.36	20.64
80	30	5.92	6.40	6.72	6.96	7.04	6.96	6.72
120		14.28	16.92	18.84	20.16	20.88	20.64	19.92
					Site index 70			
80	20	7.20	8.08	8.96	9.76	10.40	10.64	10.64
120		16.80	21.48	24.36	26.16	27.60	28.08	28.20
80	30	7.68	8.48	8.96	9.28	9.60	9.76	9.76
120		18.12	21.84	24.60	26.76	27.84	28.20	28.32
					Site index 80			
80	20	8.88	10.24	11.36	12.32	13.20	13.76	14.08
120		20.64	26.04	29.64	32.16	34.20	35.64	35.88
80	30	9.76	10.88	11.60	12.16	12.64	12.80	12.96
120		22.32	26.64	29.88	32.52	34.32	35.64	36.00

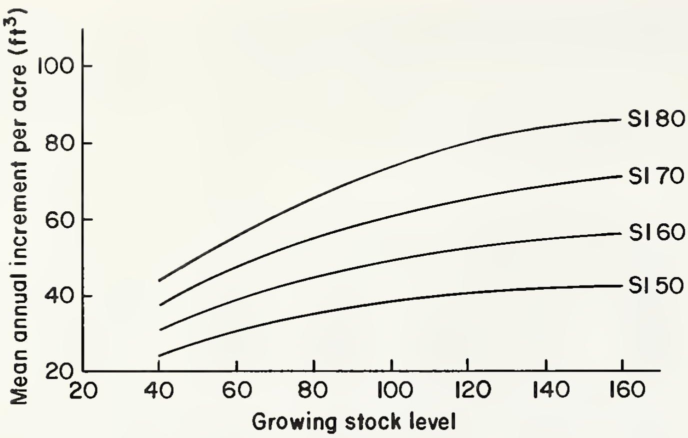

Figure 22.—Estimated mean annual total cubic-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level for a 120-year rotation, with a 20-year thinning interval (Alexander and Edminster 1981).

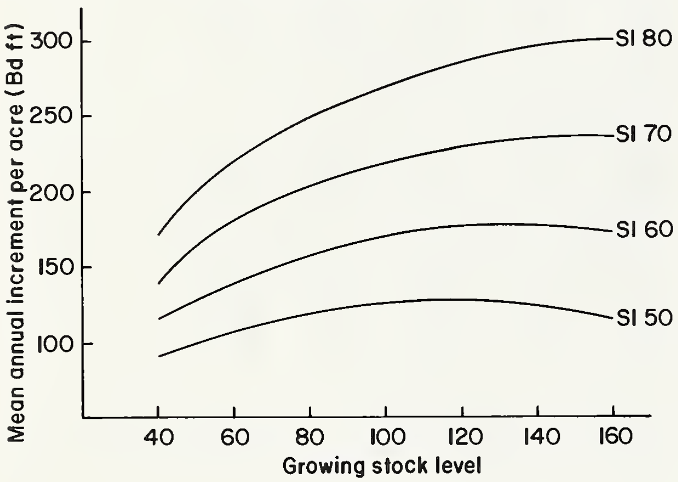

Figure 23.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level for a 120-year rotation, with a 20-year thinning interval (Alexander and Edminster 1981).

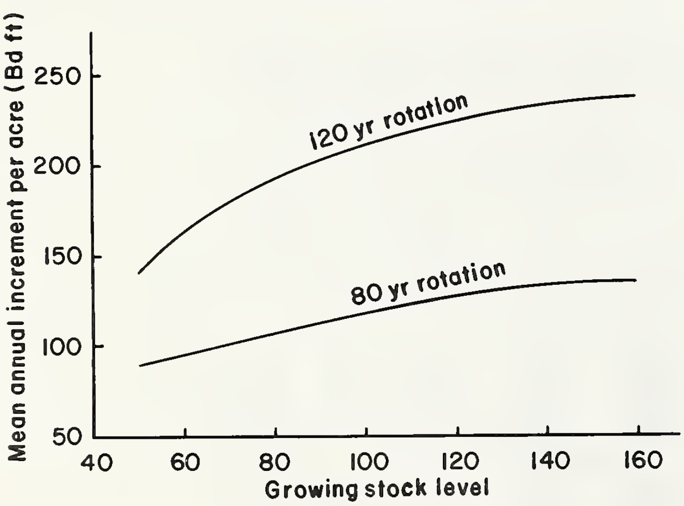

Figure 24.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine on site index 70 lands, with a 20-year thinning interval in relation to growing stock level and rotation age (Alexander and Edminster 1981).

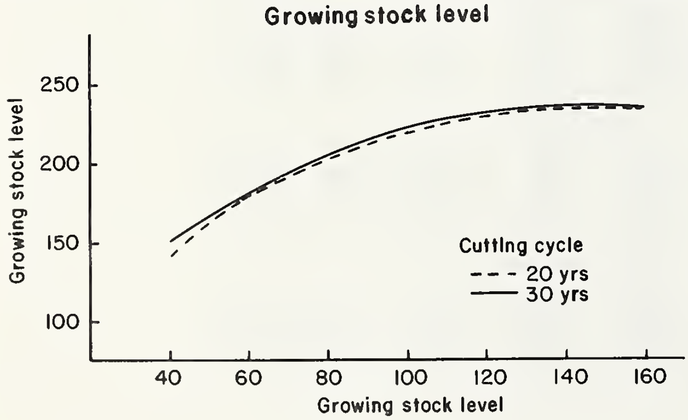

Figure 25.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine on site index 70 lands in relation to growing stock level and thinning interval (Alexander and Edminster 1981).

Table 9.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index (trees 10 inches d.b.h. and larger to an 8-inch top).

Rotation age	Cutting cycle	Growing stock level						
		40	60	80	100	120	140	160
------- *years* -------		---------- *board feet* ----------						
					Site index 50			
80	20	55	61	66	69	70	67	62
120		92	108	119	126	128	124	115
80	30	54	61	63	65	63	59	52
120		92	110	119	124	125	117	105
					Site index 60			
80	20	71	80	89	96	98	98	94
120		116	140	157	168	177	178	172
80	30	74	80	84	87	88	87	84
120		119	141	157	168	174	172	166
					Site index 70			
80	20	90	101	112	122	130	133	133
120		140	179	203	218	230	234	235
80	30	96	106	112	116	120	122	122
120		151	182	205	223	232	235	236
					Site index 80			
80	20	111	128	142	154	165	172	176
120		172	217	247	268	285	297	299
80	30	122	136	145	152	158	160	162
120		186	222	249	270	286	297	300

COST OF SALE ADMINISTRATION AND LOGGING

One of the most important factors affecting the administrative cost of selling timber is the number of entries needed for harvesting. Clearcutting and simulated shelterwood require only one entry. Seed-tree cutting requires one or two entries, depending upon whether the seed trees are harvested. Standard shelterwood requires two to three entries. Group shelterwood, individual-tree, and group selection require from three to six entries, depending upon cutting cycles. In managed stands, even-aged systems require a minimum of two additional entries for thinnings; but the number of entries under uneven-aged systems would not change.

Costs of sale layout, marking, and sale contract administration are lower for clearcutting, simulated and group shelterwood, and group selection (when groups are near the maximum size), and the final cut of a seed-tree and standard shelterwood than for individual-tree selection, the seed cut of a seed-tree, and the intermediate, preparatory, and seed cuts of standard shelterwood. Costs are reduced, because only cutting boundaries are marked, and no time is spent marking trees to cut or leave. Sale administration is easier, because there are no residual trees to protect and no opportunity to cut unmarked trees. However, reproduction must be protected at the time of final cut under seed-tree and any shelterwood system. Costs for selection methods are increased further, because good data and highly skilled individuals are required to recognize, mark, and protect trees that needed to be left to obtain the regulated distribution of diameter classes.

Timber harvesting usually requires road construction. Clearcutting is the most economical method, in terms of volume removed per unit of road, while individual-tree selection is the most expensive. Development of a transportation system to manage forests is a costly front-end investment that will require funding, in addition to the value of stumpage at the time of first entry. Once the transportation system has been constructed, road costs should be independent of cutting method.

In addition to producing maximum volume per acre in one operation, clearcutting and seed-tree cutting permit the greatest flexibility in selection of logging equipment and minimum concern for protection of residual trees. The first entry of a standard shelterwood is intermediate in volume production per acre, requires moderate concern for the residual stand, and places some constraints on selection of equipment. The final cut of a seed-tree, standard shelterwood, or simulated shelterwood has the advantages of clearcutting, except for the need to protect the new stand. Individual-tree selection requires maximum concern for the residual stand. Group selection and group shelterwood require slightly less if the size of the opening is near maximum. Under uneven-aged and group shelterwood cutting methods, volumes per entry are intermediate, size-class diversity of products harvested is maximum, and a choice of logging equipment is restricted to smaller or specialized machines.

MULTIPLE-USE SILVICULTURE

Potential Timber Yields

Natural Stands

Highest potential timber yields can be achieved under a clearcutting, seed-tree, or a two-cut shelterwood option, provided that the final harvest with a seed-tree or shelterwood is made within 5 years after regeneration is established. Comparable growth rates can be achieved with group shelterwood and group selection only if the openings are near the maximum size (2 acres). Total yields will be less under a three-cut shelterwood. Under simulated shelterwood, yield increases resulting from reduction in rotation length will be offset by the slower growth of the replacement stand. Yields will be considerably less under individual-tree and group selection in situations where very small openings are cut.

Managed Stands

The largest volume production per acre (about 36,000 fbm) is attained on site index 80 lands, at GSLs 140 to 160, on a 120-year rotation, with either a 20- or 30-year cutting cycle (table 8). These stands will contain between 60 and 90 trees per acre, with an average diameter of between 15 and 17 inches d.b.h. at rotation age (table 5).

Maximum volume production per acre on site index 70 lands (about 28,000 fbm) also is at GSLs 140 to 160; but GSL 120 is nearly as productive. Volume production declines substantially when GSL is reduced below 140 on site index 80 lands, and below 120 and site index 70 lands. The decline is greater with each successive reduction in GSL. On site index 50 and 60 lands, the largest volume production occurs at GSLs 120 to 140, respectively, on a 120-year rotation with a 20-year cutting cycle (table 8) (fig. 26).

Figure 26.—Second-growth Black Hills ponderosa pine on an average site thinned to GSL 120. Stand now averages 6.2 inches d.b.h., was first thinned in 1963, and rethinned in 1973 (Alexander and Edminster 1981).

Table 8 also shows the amount of volume given up as GSL is reduced from the level of maximum production to 40 for all combinations of stand parameters examined. Moreover, it shows that more volume can be produced over the same time span with a 120-year rotation than with an 80-year rotation. For example, on site index 80 lands, at GSLs 140 to 160, average volume production per acre on two 120-year rotations or 240 years would be about 72,000 fbm, compared with about 40,000 fbm per acre on three 80-year rotations, also 240 years.

Whether the board-foot volume production potentials can be achieved largely depends on how much money can be invested in thinning. The assumption has been made that once a stand reaches a minimum size of 5 inches average d.b.h., intermediate thinnings will be made as scheduled. If economic, social, or political constraints (such as concern about below cost timber sales) limit managers to either one precommercial thinning or no precommercial thinning[6] in the life of the stand, their options are restricted severely. For example, with only one precommercial thinning on site index 50 lands, stand density must be reduced to GSLs 60 and the cutting cycle increased to 30 years (table 10). On site index 60 and 70 lands, a GSL of 100 can be maintained with a 30-year cutting cycle, and on site index 80 lands, a GSL of 120 can be maintained.

Thinnings to a constant GSL have been assumed. However, if only one precommercial thinning is possible, managers can increase their flexibility by changing GSLs with successive reentries. This especially is important where financial resources are limited. For example, on site index 70 lands, with a 30-year cutting cycle, stand density initially is reduced to GSL 100. At the time of the second thinning, GSL is increased to 120 and increased to GSL 140 with the third thinning. Volume production will be less than maximum but reasonably close to the volume available from a stand maintained at a constant GSL 140. Attempts to raise the GSL to 140 at the time of the second entry into the stand would result in a second precommercial thinning. By following this procedure, managers also could increase GSLs on site index 50 lands from 60 to 100 (Alexander and Edminster 1980).

The manager has another option if only one precommercial thinning is possible. The initial thinning can be made on schedule and the second entry delayed until the stand reaches minimum merchantable size. This will increase the thinning interval to 40 years or more, increase the length of rotation, and result in less than maximum volume production.

If economic conditions ever permit investment of funds in two precommercial thinnings, the manager has the opportunity to maximize timber production with a constant GSL that ranges from 100 on site index 50 lands to

[6]With no precommercial thinning, the manager must try to keep initial stocking as low as possible and still maintain site occupancy; wait until the stand reaches minimum merchantable size; and enter the stand and reduce stocking to GSL 40 to 60. At these stocking levels, regeneration will establish. It is not likely that another entry will be made until the final cut. Rotations and cutting cycles will be longer than desirable, and volume production will be significantly reduced. However, direct costs also will be reduced.

140 on site index 80 lands with a 30-year thinning interval (table 10).

Managers also may elect to change GSLs with successive reentries, regardless of the number of precommercial thinnings that may be economically possible. With this procedure, the concern about retaining large numbers of trees early in the life of the stand and small numbers of trees later in the rotation can be avoided. For example, stand density can be reduced initially to GSLs 60 to 80 and successively increased to GSLs 100 to 140, depending upon site quality and cutting cycle. Volume production would be less than if density were maintained at a constant and higher initial GSL, however (Alexander and Edminster 1981).

The relationship between mountain pine beetle populations, individual ponderosa pine susceptibility, and stand density have not been determined where density has been controlled for the life of the stand. However, there is no research or experience to suggest that managed stands maintained at GSLs 100 to 140, which are below the densities of unmanaged stands with 150 to 260 square feet of basal area that are most often attacked, will be as susceptible to beetles (Sartwell and Stevens 1975).

Soil Water Resources

Water Yield

Black Hills ponderosa pine forest areas yield more water than southwestern or Front Range ponderosa pine forest areas (Gary 1975, Leaf 1975, Orr 1975). They yield less water than the subalpine forest areas in central Rocky Mountains with about the same amount of precipitation, because the source of runoff and the distribution pattern is different, and evapotranspiration demands of vegetation are higher during a longer and warmer growing season. About 25% of the precipitation is available for streamflow in the Black Hills. In the northern Black Hills where precipitation is heaviest (average 28 inches), water yields from untreated pine forests on the Sturgis watersheds averaged about 7 inches from 1964 to 1969 (Orr and VanderHeide 1973). More than 90% of the annual runoff was produced by 52% of the annual precipitation, which fell during the period of April to June. Winter snowfall is important to the recharge of soil moisture and to early runoff during the spring melt period; but it contributes little to total streamflow. Anderson (1980) reported average streamflow increases of 1.93 inches for 8 years after a partial cut on 50% of the Sturgis watershed. Increases were greatest during the wet years.

The potential for increasing streamflow in the Black Hills should be greater than the slightly more than 1 inch available from southwestern and Front Range ponderosa pine forests. The most effective pattern of timber harvest for increasing water yields is to clearcut some portion of first order basins and interbasin areas in small irregular patches, provided that conveyance and other losses are minimal (Leaf 1975, Orr 1975).

The increase in streamflow resulting from clearcutting is largely caused by reduced interception and evapotranspiration. Redistribution of snow is less important in the Black Hills than in central Rocky Mountain subalpine forests (Leaf 1975). Not only is evapotranspiration and interception reduced by removing trees in cleared patches, but soil moisture is recharged fully earlier in the growing season, resulting in more runoff and a longer runoff period than in uncut or partially cut stands (Orr 1968, 1975). The increase in water available for streamflow diminishes as understory vegetation becomes established. However, it will not return to pretreatment levels until the site is fully occupied by a new stand of trees.

Seed-tree, group shelterwood, and group selection cutting can be nearly as favorable for increasing streamflow as patch clearcutting if group openings are near the maximum size of 2 acres. In the low precipitation-high energy environment of the Black Hills, partial cutting treatments, such as individual-tree selection and shelterwood, are not as efficient in increasing water yields as they are in higher elevation spruce-fir forests in the central Rocky Mountains.

Thinning second-growth ponderosa pine also reduces soil moisture deficits, resulting in a greater potential for increased streamflow. But reducing basal area to 80 square feet, a common practice in the Black Hills, will

Table 10.—Number of precommercial thinnings of Black Hills ponderosa pine in relation to growing stock level, cutting cycle, and site index.

Cutting cycle	Site index	Growing stock level 40	60	80	100	120	140	160
years								
20	50	2	2	2	2	3	3	4
	60	2	2	2	2	3	3	3
	70	1	2	2	2	2	3	3
	80	1	2	2	2	2	3	3
30	50	1	1	2	2	2	3	3
	60	1	1	1	1	2	2	3
	70	1	1	1	1	2	2	2
	80	1	1	1	1	1	2	2

result in less water available for streamflow than at stocking levels less than 60 square feet basal area per acre.

Soil Erosion

Soil and site conditions are not the same in all Black Hills ponderosa pine forests; but many of them grow on either residual soils derived from granitic schists or alluvium soils derived from granitic rock that are medium to fine textured, easily compacted, and therefore, subject to higher volumes and more rapid runoff for a given rainfall. These soils generally are considered to be naturally erosive. When protective plant cover is removed and soils are disturbed by roadbuilding, logging, and fire, natural erosion processes are accelerated (Orr 1975). Because roads are considered the largest single cause of erosion and sedimentation in the Black Hills, careful location, construction, and maintenance of skid and haul roads is required. If this is done, roadbuilding associated with any cutting method should not cause a lasting increase in erosion.

Nutrient Loss and Stream Water Temperature Changes

Removal of logs in timber harvest represents a small and temporary net loss of nutrients, because only a minor proportion of the nutrients taken up by a tree is stored in the bole. Cutting that removes all, or most all, trees results in a greater immediate loss than partial cutting; but over a rotation, the losses would balance out because of more frequent cuts under the partial cutting methods. Furthermore, nutrients lost after cutting all, or most all, trees should be replaced in 10 to 20 years through natural cycling as regeneration becomes established. Increases in stream temperature can be avoided, even with clearcutting, by retaining a border of trees along stream channels.

Wildlife and Range Resources

Game Habitat

Mature ponderosa pine stands provide habitat for a variety of game animals. Clearcutting in small (3- to 5-acre) openings, seed-tree cutting, group shelterwood, and group selection provide the largest increases in quantity and quality of forage for big game; but use can be limited unless adequate amounts of cover are available for hiding, resting, and ruminating.

Dispersed openings of 2 and 5 acres are used more by deer and elk than smaller or larger openings or uncut timber. Very small openings provide little diversity, and game animals often are attracted only to the edges around large openings. As trees grow to seedling and sapling size, forage production and understory cover in cleared areas diminishes; but overstory cover increases until it reaches maximum in mature stands.

Standard shelterwood cutting provides less forage for big game than cutting methods that create openings; the reduction is in proportion to the density of the overstory and length of time it is retained (Pase 1958). Shelterwood cutting also provides less cover than an uncut forest. Individual-tree selection provides forage and cover comparable to uncut forests, thereby maintaining one type of habitat at the expense of creating diversity.

Partial cutting methods, except for seed-tree, in stands with an oak or aspen component, or adjacent to oak or aspen stands, provide dens, roosts, and cover for game animals, such as turkey (*Meleagris gallopavo* Linnaeus) and fox squirrels (*Sciurus nigra* Linneaus). Conversely, cutting methods that remove all, or nearly all, of the trees on a large area are harmful to their habitat.

Nongame Habitat

Information is limited on the relationship of cutting methods in ponderosa pine forests in the Black Hills to specific nongame habitat requirements; but it is possible to estimate probable effects. Clearcutting, seed-tree cutting, group shelterwood, and group selection that create small, dispersed openings provide a wide range of habitats attractive to some birds and small mammals by increasing the amount of nontree vegetation—at least initially—and length of edge between dissimilar vegetation types.

Standard shelterwood cutting provides a variety of habitats attractive to species that forage in stands with widely spaced trees, but not those that require closed forests or fully open plant communities. Under this method, trees still are available for nesting, denning, and feeding until the final harvest, when consideration should be given to retaining some of the limby live trees and snags and live trees with cavities.

Harvesting old-growth timber can be detrimental to species that nest or den in snags and in cavities of live trees, feed largely on insects, and require solitary habitats normally associated with large areas of old-growth. Most nongame species have a minimum habitat size below which they cannot exist. Small patches of varying ages and structure and all-aged stands may reduce the number of species. Individual-tree selection provides the least horizontal diversity and favors species attracted to uncut forests or that require high vertical diversity. However, snags and live tree cavities can be retained under any silvicultural system.

The low-vigor, large-limbed, or dead trees used by wildlife would be prime choices for removal if special effort is not made to save them. So few trees per acre are involved in this type of habitat maintenance that their preservation has a negligible adverse effect on the appearance of the forest and other values. Regardless of the silvicultural methods applied, these trees should remain standing as long as they are useful to wildlife.

Livestock Grazing

Historically, Black Hills ponderosa pine and associated ranges have been important livestock producing areas.

Pine and rangeland types are a complex of plant communities. Their common characteristic is open grassland parks interspersed with forested areas. Natural forested areas may be open with extensive herbaceous understory vegetation or closed with little or no understory vegetation. Forage production and changes in species composition and palatability vary considerably, depending upon plant community and successional stage (Pase 1958). Forage production increases most when clearcutting, seed-tree cutting, group shelterwood, and group selection openings are cut in dense stands. The increase in forage production in these openings persists for 10 to 20 years before competition from tree reproduction begins to reduce understory vigor and composition. It can be maintained only by frequent intermediate cuttings to keep density low. Forage production after shelterwood and individual-tree selection cutting is in relation to the amount of overstory retained and time between entries in the stand (Pase 1958, Kranz and Linder 1973).

Because understory production is inversely related to overstory density, the following regression model developed by Pase (1958) was used to estimate potential production.

$$\text{Log } y = 3.22260 - 0.00936x$$

where

y = herbage production (pounds per acre)
x = basal area (square feet per acre)
Log = logarithm to base 10

Forage production is estimated to vary from about 1,700 pounds per acre on clearcut areas to as little as 20 pounds per acre under dense stands (200 or more square feet basal area per acre) (fig 27). With 80 square feet basal area, a common density for managed stand in the Black Hills, forage production is only about 300 pounds per acre. Forage production estimated by this equation is an average for the Black Hills; actual production will vary according to habitat type.

Severson and Boldt (1977) reported on the preliminary results of a study to measure overstory/understory production in sapling and pole-sized stands of Black Hills ponderosa pine that had been thinned to GSLs 0, 20, 60, and 100 in 1963, and again in 1973. Their preliminary findings indicated that forage production was greatest under stands where GSL was reduced to 0 or 20. The combined production of wood and forage was greatest at GSLs 60 to 100, but no estimates of combined production were made at higher GSLs. This study, however, reports the results of only one measurement of changes in understory production in relation to overstory density. Consequently, these data cannot be used reliably to quantify changes in forage production under Black Hills ponderosa pine for the range of GSLs, site indexes, cutting cycles, and rotation ages examined. However, some general conclusions can be drawn from the data provided by Pase (1958) and Severson and Boldt (1977). To increase herbage production to even moderate levels (400 to 500 pounds per acre, depending upon habitat type), the manager must be willing to reduce basal area stocking to less than 60 square feet per acre (fig. 28). Moreover, to maintain this forage production, additional cuts must be made in pole-sized or larger stands at intervals of at least every 20 years.

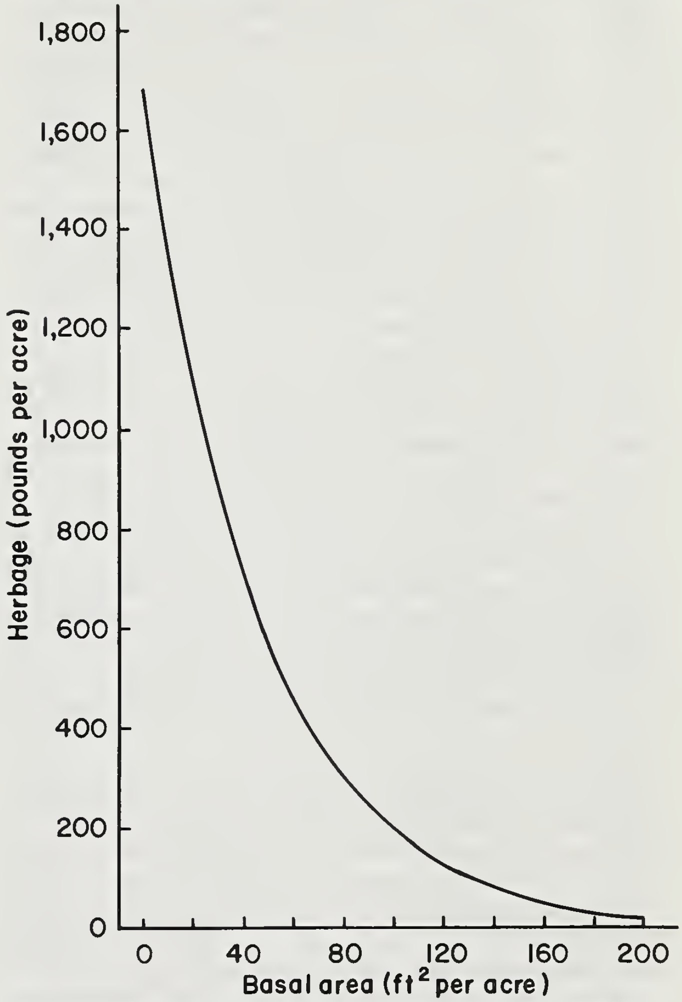

Figure 27.—Relation of herbage production to basal area of Black Hills ponderosa pine (Pase 1958).

Figure 28.—Second-growth Black Hills ponderosa pine on an average site thinned to GSL 40. Stand now averages 7 inches d.b.h., was first thinned in 1963, and rethinned in 1973 (Alexander and Edminster 1981).

Recreation and Esthetics

Ponderosa pine forests in the Black Hills provide a variety of recreation opportunities. Users who hike, backpack, or view scenery generally are attracted to forests whose natural appearance is little altered by human activities (Calvin 1972). In contrast, hunters have best success where human activities are apparent—timber sales and other areas readily accessible by roads. Fishing is done mostly in accessible lakes, reservoirs, and streams. Generally, most camping opportunities are at both publicly and privately developed sites served by roads. Most scenery viewing is by automobile on developed roads. Finally, some forms of recreation, such as home development, require major modification of the natural forest landscape.

Clearcutting and seed-tree cutting have the greatest visual impacts, and individual-tree selection the least. However, variety typical of forests whose texture is broken by natural openings is preferred to the monotony of unbroken forest landscapes (Kaplan 1973).

To enhance amenity values, cutting openings (including seed-tree) to harvest timber and improve wildlife habitat should be a repetition of natural shapes visually tied together to create a balanced and unified pattern that will complement the landscape (Barnes 1971). This especially is important for openings in the middleground and background seen from a distance. Standard or simulated shelterwood or individual-tree selection can be used to retain a landscape in foregrounds.

Selection and shelterwood cutting methods usually are most appropriate in high-use recreation areas, travel influence zones, scenic view areas, and subdivision developments where permanent forest cover is desired. The most scenic stands tend to be open-grown stands of large yellow bark ponderosa pines that typically are managed for by reducing stand density to low levels and maintaining long rotations. In the Black Hills, careful cleanup of slash and other logging debris, and location of roads historically have retained esthetic values. Virtually every acre has been harvested or thinned at least twice in the past century. A full array of cutting methods have been used in even the most visible areas.

COMPARISON OF CUTTING METHODS

No silvicultural system or cutting method (including no cutting at all) meets all resource needs. Clearcutting, seed-tree cutting, group shelterwood, and group selection that cut small openings provides maximum yields of timber at less costs, promotes the largest increases in water production without serious reduction in quality, produces a diversity of food supply and cover favored by many wildlife species, and is necessary for the development of recreation sites and home subdivisions. Production and utilization of livestock forage may be less than in larger openings, however. Cutting openings can create adverse visual effects if no thought is given to the size and arrangement of the openings; but it also can be used to create landscape variety that will enhance amenity values.

Standard and simulated shelterwood cutting also provide maximum timber yields over the same time interval but at increased costs; they produce a wide range of wildlife habitats but with less forage than openings and less cover than uncut forests. Water yields may not be greatly increased over natural streamflow, however. Shelterwood cutting provides a partial retention of the forest landscape, particularly when the overstory is retained for a long time.

Individual-tree selection cutting is not appropriate for timber production in pure ponderosa pine stands but can be used to meet other resource needs. Water yields are not greater than from uncut forests. Individual-tree selection cutting provides minimum horizontal diversity in wildlife habitat but favors species attracted to vertically diverse forests. It also provides maximum partial retention of a natural appearing forest landscape. Group selection with very small openings accomplishes about the same things as individual-tree selection.

Intermediate harvests and thinnings can be used to produce an array of resource outputs and manipulate forage and cover for wildlife. They are primary tools for dealing with mountain pine beetle and have a profound effect on both the volume and value of forest products produced.

Not all resource needs can be met on a given site, nor is any one cutting method compatible with all uses. Land managers must recognize the potential multiple-use values of each area, determine the primary and secondary uses, and then select the management alternative that is most likely to enhance or protect these values within the limits imposed by stand conditions, damaging agents, and financial resources. On an individual site, some uses probably must be sacrificed or diminished to maintain the quantity and quality of others.

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Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting methods and associated silvicultural practices needed to convert ponderosa pine forests in the Black Hills into managed stands, and maintain them, for a variety of resource needs. Guidelines consider stand conditions and insect susceptibility. Cutting practices are designed to maintain water quality, improve wildlife habitat, enhance opportunities for recreation and scenic viewing, with provide wood products.

Keywords: Silvicultural systems, timber harvesting, multiple use, *Pinus ponderosa*

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The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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RESEARCH LOCATIONS

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Flagstaff, Arizona
Fort Collins, Colorado*
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